INDUSTRIAL FUELS

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Preface

IN preparing this work the author has endeavored to treat such fuels applicable in the industries, and enable immediate comparison to be made for the selection of a fuel for a specific purpose

The scope of the subject is unusually broad, and would require several volumes to treat in anything like a conclusive manner. In this volume, however, the limited time of the practical business man has been kept in view, and the work is written in a brief, concise manner to comply with his needs; whilst the scientific investigator will find food for thought in the application of nature's heat and subsequent conservation for material use.

Respectfully submitted,

THE AUTHOR.

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COAL

INTRODUCTION. The most important epoch in the history of the world is the *period of stratification*, and on it the formation of coal has been greatly influenced. The world previous to this period is considered to be merely a rolling ball of solid matter, and its development to its present form has been brought about by the action of water and the firmament influenced by the sun. The earth first solidified at the crust and ultimately commenced cracking, shrinking and bending, and these convulsions altered the entire surface and caused vast quantities of animal and vegetable matter to be compressed by the overlying strata which has matured during the countless ages and formed an inexhaustible supply of valuable fuel.

The constant repeating of this process has resulted in many different deposits, so that the oldest are located at the greatest depth unless they were moved by later convulsions. There is little doubt that these movements occurred during the time of the formation of stratified rocks, and there is evidence which corroborates the theory that nearly all exposed land surfaces have been again and again submerged beneath the ocean, and that sea deposits have been again and again raised to a great height above their present level.

SEAMS: In carboniferous times there was a growth of vegetation more prolific than had ever been possible in previous history or has been possible since. The condition of the atmosphere, soil, heat, and moisture were exceptionally favorable to luxuriant growth. It is generally believed that a tropical heat existed over the whole earth; a condition on which different theories have been made. It has been claimed by some scientists that the earth was nearer the sun than at present, and, therefore, was heated with greater intensity; while others claim that the atmosphere was charged to a greater extent with carbon dioxide, which stimulated the growth of plants and served to retain the genial warmth of the sun.

During the period of the rich growth of vegetation, the great convulsions and upheavals of the earth were taking place, which caused the primeval forests to be overwhelmed and buried beneath the water and vast accumulations of earth and sediment. The convulsions have been repeated and caused alternate elevation and subsidence with the depositing of sand and shale in the lower regions. The water has eventually gravitated to the lower regions, and conditions suitable for plant growth have again prevailed. The formation of coal in seams is undoubtedly caused by a repetition of the process, and each seam represents the period when the water was driven back and vegetation enabled to flourish. The intermediate strata represents periods during which the decaying vegetable matter was submerged and gradually covered by accumulations of sand and sediment.

The theory that coal originates from organic matter is strengthened by microscopic examination in which the vegetation structure can be observed, and ferns or branches may be found impressed as fossils on the roof of the seam, or roots of trees may be discovered in the underclay. The greatest evidence, however, is its composition, and chemical analysis proves it to have the same elements as wood. These, however, are in varying proportions which has been caused by the changes undergone in the period of its deposition. The process by which vegetation has been transformed into coal, and the cause of its varying qualities, are subjects of great importance. It is obvious that the thickness of coal seams is accounted for by the abundance of vegetation, or the length of the period during which growth was uninterrupted. The transformation of vegetable matter into coal has undoubtedly been influenced by certain agents, of which the following are the most important:

(1) The terrestrial heat.
(2) The heat generated in the decomposition of the organic matter.
(3) The pressure of the overlying strata.
(4) The convulsions and volcanic eruptions.
(5) The length of time during which the matter has been submerged.

The fuels which have experienced the least alteration are peats and lignites. These are found nearer the surface and contain less carbon than coal, and have lower densities. They are evidently the results of later growth, and have therefore not been subjected to as many influences of the earth as coal. The most important agent is the heat of the earth, which becomes greater as the pressure of the overlying strata increases. The most complete form of coal or anthracites are therefore generally found at greater depths.

It is obvious that coal is the result of the distillation of the original vegetable matter caused by terrestrial heat and the heat generated in its decomposition; and that the final nature of the fuel is dependent on the amount of hydrocarbon or other volatile gases which have escaped during decomposition. This, in combination with other agents which have assisted or retarded the escape of the gases, have been the means of influencing the composition and character of the final product.

The seams of coal which have suffered the greatest metamorphism are those overlain by porous rocks which have allowed the gases to escape, and as the rock formations of more recent times may be as porous or more than ancient rocks, it is not necessary that the fuels which have undergone the most complete distillation are the oldest, although it is obvious that seams which have been covered with impermeable rocks and buried under vast accumulation for a greater time will have undergone the greatest changes.

The depositing of coal seams according to the aforesaid principles is known as the *in situ* theory, and there is very strong evidence that the greater portion of coal originated according to this theory. However, there are some seams which do not appear to have been deposited in this way, and their origin has been attributed to the *drift theory*. The theory of coal formation by drifts is supported by many who contend that great masses of decayed vegetable matter were carried from vast swamps by streams of water into lakes or estuaries. When the water became stagnant, it is supposed that the vegetation floated on the surface and spread out uniformly over great areas until it finally sank to the bottom. The lakes eventually became filled with sand, mud, and other debris washed down by the rivers which covered up the vegetation and formed the strata now found above the seams. The fact that many beds of fireclay are found without any sign of coal above them, and also that seams of coal are found without any fireclay beneath them provides some evidence on the accuracy of this theory when it is considered that fireclay is the result of the absorption of lime and alkalies of the soil by the roots of growing plants. There is also evidence in the seams themselves in the presence of thin portions of shale which has not been penetrated by the roots of plants above them. These partings frequently thin out in one direction and disappear entirely, while in the opposite direction their thickness increases until one seam becomes two with many yards of strata between them. This is consistent with the theory that debris has been carried down into large areas and deposited according to their relative specific gravities.

The so-called *Cannel Coal,* which is also considered to be of maritime origin, possesses further evidence of the drift theory in that it contains a comparatively large amount of fish remains, shells, minute crustacea and mineral ash. This coal, however, is unlike other coals in these respects, and the seams are variable in thickness and limited in extent which suggest that they may have been formed either by the "drift" or "in situ" process.

In consideration of the varied theories and natures of coal, it may safely be claimed that whilst it undoubtedly results from vegetable matter, the process of its formation varies somewhat, and that some beds are results of one process, whilst other seams have been subjected to different processes.

CLASSIFICATION: The classification of coals is made in different ways, the most important of which are according to:

(1) The physical characteristics.
(2) The chemical composition.
(3) The calorific or heat value.

Each method of classification has certain industrial or scientific advantages, and will be referred to in the order given.

PHYSICAL CHARACTERISTICS: The most common classification is based upon the physical characteristics, such as color, density and structure. In this method of classification the fuels are divided into the five classes—Wood, Peat, Lignite, Coal, Anthracite.

Wood: In the study on the formation of coal, it has been shown that fuels originate from vegetable matter, in which wood is the first stage of its formation. The heating power of most kinds of wood is about the same per pound, and is about .4 of the value of the same weight of coal.

Peat: The first product resulting from the decay of vegetable matter is peat, which is found in bogs, swamps or other low-lying marshy places. It consists chiefly of ferns, mosses, rushes, reeds, and other plants of a similar nature. Its composition varies like other fuels and has no doubt been influenced by the variations of heat, pressure, time and geological conditions. The percentage of carbon varies from 50 to 65; hydrogen from 4.5 to 7.00; oxygen from 28.5 to 44.00; and nitrogen from 0.00 up to 2.5. It also contains a large amount of moisture, and retains about 25 per cent. in the atmosphere. The calorific value of one pound of air-dried peat is about 12.000 B.Th.U., whilst that of artificially dried peat is somewhat higher according to the degree of the expulsion of moisture. It has a disadvantage for use in metallurgical purposes owing to the phosphates and sulphur compounds contained in the ash.

Lignite: This is the first product which comes under the heading of coal, and is frequently referred to as *brown coal.* It is chiefly found in tertiary rocks. Its composition is about 65 per cent. carbon; 5 per cent. hydrogen; 30 per cent. oxygen; and it contains from 10 to 30 per cent. of moisture. It has a woody structure, breaks easily in transportation, and has the appearance of having shrunk but not compressed. It burns with a yellow flame, emits a disagreeable odor, and has a heating value of from 10.000 to 14.000 B.Th.U. per pound; the latter figure being obtained only in bituminous lignite, which is the most concentrated class. Its specific gravity varies from 0.5 to 1.25.

Coal: The different classes of coal may be divided into Gas Coal, Bituminous, Semi-Bituminous, Anthracite. The relation between these classes is very gradual and there is not a distinct line between them. The lignite referred to in the last paragraph is the first stage, and this develops first to bituminous lignite and then to the non-caking bituminous coals. The gradation then follows to gas-coal, bituminous, semi-bituminous and anthracite.

Gas Coal: The decomposition of all fuels results in the formation of gases, and are, therefore, technically all gas coals. The term, however, is applied to those coals which give off large quantities of volatile gases when heated, and they may be divided into Brown Coal, Cannel Coal and Hard Coal. They are generally of a brownish-black, and conchoidal in structure. They burn freely with a long flame, and may be either caking or non-caking. The caking class is rich in volatile matter, gives off from 30 to 40 per cent. on distillation, and produces from 60 to 70 per cent. of porous coke. The calorific value varies from 14.000 to 17.000 B.Th.U. per pound. The non-caking class are nearest in composition and nature to lignites, and when distilled they leave a coke which is fine and powdery.

One of the best known coals used for the manufacture of artificial gases is *Cannel.* It is chiefly used in gas plants for enriching gases from bituminous or other lower grade gas coals, and is frequently referred to as "candle coal." It differs somewhat from ordinary bituminous coal, is very compact, dull in appearance, does not soil the hands, and breaks with a smooth conchoidal fracture. It usually retains its original structure after distillation. The composition of cannel is much the same as certain classes of bituminous coal, and differs only in physical characteristics brought about by unusual conditions in its formation.

Bituminous: The bituminous are slightly more concentrated than gas coals, and contain more carbon and hydrogen and less oxygen. They are found in both the caking and non-caking class, and in three distinct varieties, namely, *Flaming, Clear-Burning, Fuliginous.*

The flaming coals are the true caking coals and are frequently known as *soft coals.* When these coals are heated they lose their original structure and fuse together to form a spongy mass through which the volatile matter escapes. On burning this fuel in an open grate, the gas is seen to intermittently spurt out as a narrow tongue of flame, and is followed by a small but dense stream of unkindled smoke. This class of coal is used considerably for the manufacture of gases for commercial distribution.

The *clear burning* coals are very similar in structure to gas coals, and break up into small regular lumps. The flame from these coals in generally clear and shorter than from gas coals. The percentage of volatile matter is less and the amount of coke produced is proportionately higher. The clear burning fuels are valuable for use in coke-oven plants where the amount of coke produced and value thereof is the first importance.

The *fuliginous* or smoky coals are also rich in volatile constituents, and therefore produce a large volume of gases. Their coking properties are not so great as the flaming coals, and therefore produce a poorer grade of coke. They are best suited for steam raising or gas making. The sooty character of their flame renders them unsuitable for domestic use.

Semi-Bituminous: This class of coals are between bituminous and anthracite, and are usually found at greater depths than the bituminous or gas coals. They are, consequently, more dense than the fuels referred to, and contain more carbon and less volatile gases. The amount of carbon may be from 80 per cent. up to 92 when they gradually pass into anthracite. They possess a good black color, a conchoidal structure, and are much harder than the aforesaid fuels. It burns with a short flame and emits little smoke when there is a full supply of air. This fuel is used for all industrial purposes and is especially suitable for domestic use. The calorific value is from 12.000 to 16.000 B.Th.U. per pound.

Anthracite: This is the most complete form of coal, and consists chiefly of carbon, and has evolved practically all its volatile matter. It is the results of great geological pressure and particular conditions of its deposition and formation. It is dense black in color, hard and lustrous, and has apparently been more completely mineralized. It burns without smoke or flame, generating intense local heat, but is somewhat difficult to ignite and requires a strong draft for combustion. It is extremely brittle and requires careful stoking to prevent it from falling to pieces. It is non-caking, and its coke residue is powdery and has no commercial value. Its calorific value is about 15.000 B.Th.U. per pound.

CHEMICAL COMPOSITION: The composition of coal forms the most important evidence that it is a derivative from vegetable matter, and a reference to the following table, which is compiled by Andre, is a proof of its gradual development into anthracite:

TABLE 1.
COMPOSITION OF FUELS.

Substance	Spec. Grav.	Carbon	Hydrogen	Oxygen and Nitrogen
Wood	0.91	49.00	6.25	44.75
Peat	0.90	59.30	6.52	34.18
Lignite	1.25	73.37	5.18	22.45
Cannel	1.27	80.37	5.83	13.80
Bituminous	1.30	86.17	5.21	8.62
Semi-Bituminous	1.37	90.00	4.75	5.25
Anthracite	1.50	92.50	3.75	3.75

In order to determine the heat value of coal from its chemical composition, it is first necessary to allow for a certain amount of carbon or hydrogen required to combine with the oxygen already present in the coal. When the oxygen conbines with the carbon it produces carbon dioxide CO_2, and with hydrogen it produces water H_2O. The deduction is usually made from the hydrogen which considerably reduces the quantity available for combustion by the oxygen of the air. The formation of water from the combustion of hydrogen is objectional to a fuel, in that it requires a portion of heat to drive it off as vapor. The proportion of moisture in coal is, therefore, a very important factor in the calculation of the heat value. It is frequently referred to as "water of hydration," or that part of volatile matter which is incombustible or inert so far as the fuel value is concerned.

The heating value of coal can be obtained from its chemical composition by *Dulong's Formula*, and accepted as being correct within limits of less than 5 per cent., the deviation from the true calorific value varying with the composition of the coal.

The formula referred to is:

$$V = 14600C + 53.300\ \left(H - \frac{O}{8}\right)$$

in which V = Heating value of coal per pound in B.Th.U's.
C = percentage of carbon expressed decimally.
H = percentage of hydrogen expressed decimally.
O = percentage of oxygen expressed decimally.

Hence, if a coal has a composition of 80 per cent. carbon, 6 per cent. hydrogen, and 8 per cent. oxygen, the heat value per pound will be as follows:

$$14.600 \times .80 + 53.300\ \left(.6 - \frac{.8}{8}\right)$$

$$= 11680 + 2665 = 14.345 \text{ B.Th.U.}$$

CALORIFIC OR HEAT VALUE: The calorific value of a coal is undoubtedly the most important in selecting a coal for a certain purpose, and whilst an approximate value may be obtained from its chemical composition, it is also dependent to a certain extent on its physical characteristics and behavir when heated. The different conditions under which coal is burnt must be considered in selecting a coal particularly adaptable to the purpose.

In the consideration of a fuel for domestic use, it is desirable to select one which burns with little or no smoke, and for economical use it should require as little draft as possible. The employment of anthracite for this purpose cannot be claimed to be efficient in that it generates intense local heat, and is difficult to ignite. The localizing of heat causes one part of the building to be heated too much at the expense of another, whilst the necessity of a strong draft to burn the fuel causes a comparatively large portion of combustible gases to be lost up the chimney.

The selection of a fuel for an industrial purpose varies with the conditions, and, in many cases, it would be more economical to select or modify apparatus in which it is consumed in order to obtain the greatest value from the fuel. For instance, in the generation of steam, the employment of water-tube boilers, rocking grates, economizers, smoke consumers is an indication of the great difference in the qualities of various coals, and the necessity of adapting methods of combustion to the fuel used. The adoption of special apparatus for a given purpose is a subject which can only be decided by the power engineer in charge, and whilst in some cases a steam boiler and engine is desirable, it may safely be claimed that by the employment of gas engines and gas producers a greater portion of heat units of the fuel can be converted into power.

The value of coal is largely dependent on the amount of carbon, hydrogen, and oxygen, and when used for steam boilers, a computation of the heat units by *Dulong's Formula* is usually sufficient. In the selection of a coal for gas producers there are other qualities which influence its efficiency, and the following qualities are usually considered:

(1) Moisture.

(2) Ash.

(3) Sulphur.

(4) Combustible Volatile Matter.

(5) Coking Properties.

(6) Strength and Hardness.

(7) Specific Gravity.

Moisture: The value of coal is greatly influenced by its percentage of moisture and its ability to absorb or expel it. The exact determination of the amount of moisture present in different varieties of coal is a difficult matter, as some coals lose moisture rapidly when broken up, whilst others have a tendency to absorb it. The amount of moisture in commercial coal varies with its nature, the degree of fineness and weather conditions. The brown coal or lignite invariably shows a greater proportion of moisture at the point of consumption than at the seam, and bituminous coal which has less than 5 per cent. at the seam will show more after being exposed to the air, and less when the original moisture is more than 5 per cent. As a rule, lump coal will contain less moisture after being exposed to the air, whilst fine coal or slack is influenced considerably by the weather. A car of slack which has been out in wet weather may contain as high as 15 to 20 per cent. of surface or loosely held moisture. It is very important that the moisture question should be carefully considered in determining the value of "washed coal," as these coals must necessarily be reduced to slack before the washing is effective, and unless they have been subjected to a thorough drying a considerable loss is experienced when it is remembered that 1 per cent. of the moisture is equal to 20 pounds per ton.

Ash: The ash is the residue which results from the complete combustion of coal, and consists essentially of mineral matter inherent in the coal and varying quantities of other impurities. Its composition is chiefly silica, oxide of iron, alumina, lime, and traces of magnesia, potash, sodium, and calcium sulphate in varying proportions. An analysis of the ash from five different grades of coal gave the following composition:

TABLE 2.

COMPOSITION OF ASH

Compound		Grade A	Grade B	Grade C	Grade D	Grade E
Silica	SiO_2	65.60	44.80	32.05	15.42	3.15
Alumina	Al_2O_3	28.40	22.93	8.53	5.68	25.40
Ferric Oxide	Fe_2O_3	2.25	25.63	53.35	73.80	35.80
Calcium Oxide	CaO	1.40	2.75	3.43	2.07	21.15
Magnesia	MgO	1.15	0.65	1.75	0.23	2.23
Potash	K_2O	2.30	0.63	0.22	0.47	1.17
Sodium Oxide	Na_2O	....	0.31	0.25	....	1.87
Calcium Sulphate	$CaSO_4$	....	2.30	0.42	2.33	9.23

The ash is like moisture in that it reduces the commercial value of the coal. Its elimination at the mine involves considerable expense in labor, and at the point of consumption its formation into huge masses of clinker is a serious drawback in many industrial processes. It differs somewhat in appearance according to its constituents and methods of combustion, and is generally seen in the domestic furnace in white flakes, whilst in the industries it is seen as a fused, vitreous mass which is termed "clinker."

The fusibility of ash is dependent chiefly upon the chemical composition and physical properties, although the temperature of combustion has considerable effect on the condition of the clinker. The fusibility of the ignited ash is dependent upon the ratio of the silica to the bases present, and upon particular bases and the percentage of alumina. Ash which is high in silica and high in bases does not fuse as readily as those approximating uni-silicate, although frequently those up to bi-silicate and even tri-silicate composition are fusible at temperatures from 1800° to 2200°F. By reference to Table 2, it is seen that grades A-B are highly silicious and low in iron and are consequently not readily fusible, whilst in C-D the formation of ferrous silicates will take place at a temperature of about 2000° to 2200°F., respectively.

The percentage of ash in any one particular grade of coal is so variable that it is almost impossible to make a definite specification, and it may occasionally be as low as one per cent. in clean lumps of coal and as high as 25 per cent. in slacks. In good classes of coal it is usually in the region of 6 per cent., and from 10 to 15 per cent. in slack coals.

Sulphur: The presence of sulphur in coal is a disadvantage for practically all purposes. In the manufacture of gas, the volatile sulphur will produce hydrogen sulphide H_2S, which is an impurity which must be removed before distribution owing to its poisonous nature and disagreeable odor. The sulphur content which remains in the coke is also objectionable, owing to its tendency to produce sulphuric acid, which is a corrosive.

It chiefly occurs in coal in the form of iron pyrites FeS_2, when it appears in yellow or brassy partings; as an organic compound with carbon and hydrogen; and as sulphate of lime and alumina. The heating value of sulphur varies somewhat according to its combining elements, and may either evolve heat or absorb it. The unoxidized sulphur will on combustion be burned to SO_2 with the evolution of heat; whilst when it combines with iron or calcium it has no heat value, and the decomposition of the sulphates absorbs heat. The balance of heat obtained is, therefore, comparatively small and the sulphur dioxide formed combines with water on cooling in the flues and forms sulphurous acid, which on further oxidation, is converted to sulphuric acid.

The amount of FeS_2, which is the chief sulphur compound, has considerable influence on the formation of clinker, and the oxide of iron produced by combustion combines with the other constituents of the coal which are usually highly silicious and readily produce fusible silicates or clinkers.

COMBUSTIBLE VOLATILE MATTER: The percentage of volatile combustible is one of the chief factors in the adaptability of a coal for an industrial purpose. In the manufacture of gas the value of coal is increased as the volatile constituents increase; whilst for domestic use, a coal with more carbon and less hydrocarbons can be more completely burned and is, therefore, more económical. For general use the advantages and disadvantages of a coal high in volatile combustible may be determined when the following facts are considered:

(1) That when a large percentage of volatile combustible is present, the coal easily ignites and burns with a long flame.

(2) That the surface temperature of a red-hot fire is temporarily lowered when coal is added, by the absorption of heat required to drive off the volatile matter.

(3) That the hydrogen produces moisture on combustion, and that moisture has a tendency to prevent complete combustion of carbon by keeping the temperature below the ignition point.

(4) That a temperature slightly below the ignition point will liberate bodies which are rich in carbon and cause them to pass of as smoke.

(5) That the rate of distillation of hydrocarbons is considerably greater than the oxidation of the carbon residue, which causes an insufficient supply of air for combustion at one stage of the decomposition or a considerable excess at another.

From the above conclusions it is evident that whilst volatile combustible is capable of giving off the greatest amount of heat, the methods at which it must be fed to a fire prevent complete combustion, with the result that a considerable loss is experienced.

It is seen from Table 1, page 8, that the percentage of carbon increases as the metamorphism of the vegetable matter becomes more complete, and simultaneous with this, the percentage of hydrogen and oxygen decreases. The coals high in carbon are the most valuable for general use, and the writer believes that the less concentrated coal will in future be subjected more to artificial means of removing the volatile matter where it can be recovered and rendered more productive.

COKING PROPERTIES: The coking properties of coal are greatly influenced by the percentage of available hydrogen or hydrogen that has not taken up oxygen. The first stages of coal such as lignite or peat contain a large amount of oxygen, which combines with the hydrogen when the temperature of the fuel is raised, and reduces the amount available for entering into combination with carbon. These coals are, therefore, non-caking. As the coal becomes more concentrated, as in the Cannel or Bituminous classes, the percentage of oxygen becomes less and the available hydrogen greater. When these coals are heated in a closed retort or open grate they lose their original structure and cake together into a new form. As the coal becomes more concentrated to SEMI-Bituminous or Anthracite, it contains more carbon and less hydrogen, and coincident with this change it loses its coking properties.

STRENGTH and HARDNESS: The strength and hardness of a coal is an important factor, and on it the proportion of slack produced in transportation depends. Coal that is easily broken is of little value in many industries, particularly in blast furnace practice where a great pressure is brought down upon it, as its disintegration to dust obstructs the path of air for combustion. The breaking up of coal into small particles exposes a greater surface to the atmosphere with the result that the percentage of moisture is considerably increased, and the coal is more liable to spontaneous combustion or oxidation. The latter results in the loss of some volatile gases which lower the value of the fuel for gas manufacture, but the retort process has the advantage of coking such coals and rendering more useful in the industries.

SPECIFIC GRAVITY: The gravity of coal increases as its development becomes more complete, as will be seen from Table 1. There is little or no relation between the gravity of coal and its composition and character, but a knowledge of the gravity is of some value in computing the approximate weight of coal in a car or storage hopper from the cubical capacity.

GEOLOGICAL SURVEY: The presence of natural gas has been known for many centuries in British India and other parts of the Orient, although it was not put to commercial use until 1872. In the far-east it appeared as leakage from the gas-bearing strata through crevices in the ground, and was worshipped by the natives as a "fire god."

The first discovery of natural gas by drilling occurred in U. S. A. by the drilling of wells for salt in Ohio and West Virginia in the early part of the nineteenth century. It was not, however, until 1872 distributed for domestic use. This occurred at Titusville, Penn., which received gas from Newton, about 10 miles north, on a 2-inch line.

The origin of natural gas is a subject on which many theories have been put forward, and whilst no one theory is conclusive, each may claim to be in a certain measure correct, and it is generally believed that the various reservoirs are not of a single origin. Natural gas has been found in various parts of the world under practically every climatic condition. It is frequently associated with oil, which is the product of natural gas caused by the pressure and confinement of the gases in the rocks. The most reliable theories may be classified as (1) The Organic; (2) The Inorganic.

The *organic* theories appear to have the strongest claims and are generally accepted as being the most reasonable. The most important of these is the *sea-weed* and *diatom* theories, which claim that natural gas and crude oil are the results of the decomposition of marine plants and diatomaceous shales in the same manner that coal is the decomposition of land plants. The *land* theory is somewhat similar and claims that it results from vegetable matter found in swamps, marshes and lake beds, and is associated with the formation of coal. The presence of coal in many gas and oil fields supports this view, and also the fact that the distillation of bituminous coals will yield hydrocarbons similar to those found in crude oil.

The *inorganic* theories may be divided into the *carbide or hot-water* theory, and the *volcanic* theory. In the first of these it is assumed that under certain conditions of pressure and temperature, carbon is caused to combine with calcium iron, and other metals, and form carbides, which when subjected to the action of hot water brought into contact with them by sudden movements of the earth are caused to generate hydrocarbons of varying composition. *The volcanic* theory is strongly advocated by many investigators, in which conclusive proof is claimed. One of the most interesting papers of recent times on this subject is written by Eugene Coste, E.M., Toronto, Ont., and published by Canadian Mining Institute, Vol. 6, 1903, from which two important paragraphs are reprinted:

> (1) "As everyone knows carbon is the fundamental element of the organic world, but this must not blind us to the fact that carbon is also an important element in the mineral world. Indeed, the predominance of carbon in the organic world is one of the strongest evidences that can possibly be adduced to demonstrate its great importance, during past as well as present ages, in the mineral world (including of course the atmosphere), for vegetables and animals alike have evidently no other source to draw from. When one reflects on all the carbon subtracted from the mineral world during the past geological ages by all the representatives of the organic world, especially since the beginning of the Carboniferous, to form not only the coal beds, but the limestones, he must admit that primitive atmosphere was very rich in carbon.
>
> Therefore large quantities of this element must have been dissolved in the first fluid of magna of the earth, and large quantities of it must still exist in the fluid magna of to-day under the crust of the earth."

(2("The present daily production of the hydro-carbon acetylene by the simple action of water on carbide of calcium is very suggestive, and these consideration together with a further one, now proved and admitted, that eruptive magnas are hydato-progenic, namely; contain the more or less notable admixture of water necessary to suggested possible reactions in the formations of hydrocarbons are sufficient in that resyect. The vital point is to actually show the carbon and hydrocarbon in the ingneous rocks, lavas and emanations proceeding from these internal fluid magnas. That, geology can do and has done, in a great many instances, at points widely distributed over the whole surface of the globe; and we will now past in review a few of these instances, namely:

First.—In the Archaen rocks we find carbon under the form of graphite in gneisses, in pegmatite dykes, in granites, gabbros and other rocks, the igneous origin of which is undeniable.

Second.—In the crystals of igneous gneisses and of most granites and other eruptive rocks, gaseous and liquid inclusive are most abundantly found, and these are very often constituted by carbonic acid and hydrocarbons, and also often contain chloride of sodium in solution or in minute crystals.

Third.—Petroleum, or semi-liquid or solid bitumens have often been noticed and cited by many observers as occuring in traps, basalts or other igneous rocks.

Fourth.—Volcanic rocks forming vertical necks and pipes across horizontal strata ahd containing carbon in the pure form of diamonds are also well known to constitute in South Africa the deposits of these precious stones.

Fifth.—I now come to the hydrocarbons and carbonic acid in volcanic manifestations of today. Not later than a few months ago the civilized world was startled and horrified at the report that an explosion of Mount Pelée had wiped away in a few minutes the entire population of the City of St. Pierre, Martinique Island. From the accounts of the catastrophe then published, it is quite evident that a fearful blast or tornado of gases suddenly shot from the side of the volcano, asphyxiating and burning in a moment 30,000 people. Nothing else, I submit, but gas would carry death so suddenly to so many thousand people, inside and outside of their houses, over a whole city. That these gases were mostly sulphur gases and very inflammable gases (which could be mainly nothing else but hydrocarbons) has also been made clear by the accounts of the very few survivors.

In view of the aforesaid theories, the writer is of the opinion that natural gas is not of a single origin, and its formation has occurred in much the same manner as coal, and has been subjected to various influences of the earth. However, the theory of its accumulation into commercial deposits has been developed with remarkable success.

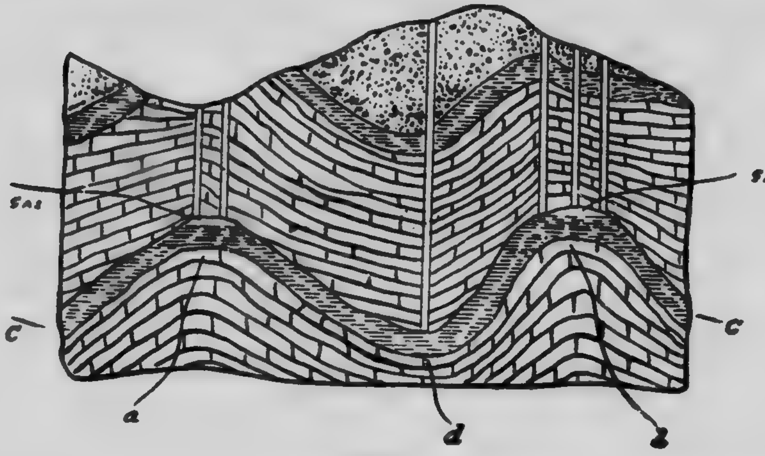

Figure 1

The greatest developments of gas and oil bearing regions has undoubtedly been made in the United States of America, and in the majority of cases the strata are sandstone of various geological formation in the shape of several distinct layers. From the observations of various experts, the following facts are recognized:

(1) That oil collec in an *anticlinal* strata at the highest part of the fold.

(2) That the lowest part or *syncline* of the same strata, a deposit of water will always be found.

(3) That the deposits occur in sedimentary rocks, shales, sandstones and limestones.

(4) That at the uppermost part of the strata, natural gas will always be found.

The above conclusions will be best understood by reference to Fig. 1, in which *a* and *b* are the anticlines of the strata *c*, and the point at which oil will be found; whilst *d* is the syncline of the same strata from which a deposit of water will always be found.

GAS WELLS: The extraction of natural gas and crude oil from its deposits is met with difficulties of various degrees according to the location of the deposit. In different parts of the Orient oil is known to have been collected in shallow wells dug by hand, but the general procedure entails the drilling of wells which may be as deep as 7,000 feet or more.

The first step preceding the drilling of wells is to obtain a *lease* on theland, which may be made on a straight yearly rental as in the case of real property, or on a basis of a specified amount for each well drilled in which gas in paying quantities is found. The latter agreement is the most common.

The lease usually has reference also to the quantities of oil produced. The land owner generally receives from one-eighth to one-sixteenth of the total value of oil produced during the life of the well, whilst the operator is given an exclusive right to drill and a right of way for pipe line across the land.

DRILLING: It frequently happens that the operator does not undertake the drilling, and when such is let to a contractor, the agreement is based upon a price per foot of completed hole. In locating a well it is first necessary to give some consideration to a supply of water for steam raising, and also the location of the boiler on the windward of the derrick with reference to prevailing winds. If the geological survey forecast a large flow of gas the boiler should be located some distance from the derrick for safety.

The *derricks* used for drilling gas wells are divided into two general classes: (1) The Standard; (2) The Portable. The portable rig is generally employed for drilling up to 1,000 feet, after which it is necessary to use permanent or standard rigs. The latter are divided into the *cabletool* system or the *hydraulic rotary* system according to geological condition.

The standard derrick may be of steel or wood, the latter of which may be either bolted or nailed. The wood are more commonly employed owing to the greater ease at which they can be removed or repaired. The bolted derrick is to be preferred to the nailed derrick as it can be taken down and rebuilt with less breakage, although its initial cost is slightly greater. For temporary employment where a gas well is drilled for private use, the nailed derrick is satisfactory. The height of a standard rig is from 74 to 84 feet.

The depth of wells vary from 200 to 7,000 feet or more according to the geological survey, and the diameter of the holes varies accordingly. A deep well usually starts with a 10 to 14 inch hole and finishes with a hole from 4 1/8 inch up. As the drilling proceeds, a drive or conductor pipe is placed in the hole to prevent caving in, and may be either iron or wood. The iron pipe is necessary for deep wells, whilst the wood conductor may be satisfactorily employed in shallow wells, and is cheaper than the former. The hole is reduced in size as the drill proceeds, each reduction being made after the casing is put in, after which the well is allowed to stand for a short time to determine whether the hole has been cased dry. The drive pipe and casing used is of special size so that one fits inside another with a close joint. For instance, if the hole is started at 14 inches, the drive pipe used will be 12 inch, the couplings of which have an outside diameter of 13 31/32 inch. If a 9 5/8 inch casing is put in this at first, the next reduction will be to 8 1/4 inch, the couplings of which are 9.312 inches on the outside and fit into the first casing.

TABLE 3.

DIMENSIONS OF DRIVE AND CASING PIPE.

DRIVE PIPE.

Size of Pipe	Diam. Outside Inches	Weight per Foot Pounds	Threads per Inch	Outside Diam. of Couplings
3	3.437	7.54	8	4.125
4	4.460	10.66	8	5.250
6	6.532	18.76	8	7.500
8	8.687	28.18	8	9.594
10	10.719	40.06	8	11.969
12	12.750	49.00	8	13.969

CASING.

Size of Pipe	Diam. Outside Inches	Weight per Foot Pounds	Threads per Inch	Outside Diam. of Couplings
3	3.250	3.960	14	3.781
3.250	3.500	4.280	14	4.000
3.500	3.750	4.600	14	4.250
3.750	4.000	5.470	14	4.625
4.000	4.250	5.850	14	4.687
4.250	4.500	6.000	14	4.937
4.500	4.750	6.550	14	5.218
4.750	5.000	7.580	14	5.562
5.000	5.250	8.000	14	5.781
5.187	5.500	8.400	14	6.062
5.625	6.000	10.160	14	6.062
6.250	6.625	11.500	14	7.125
6.625	7.000	12.450	14	7.687
7.250	7.625	13.500	14	8.220
7.625	8.000	15.000	11.5	8.625
8.250	8.625	16.000	11.5	9.312
8.625	9.000	17.500	11.5	9.750
9.625	10.000	21.000	11.5	10.812

In additional to the above there are several grades of pipe of the same sizes in which the material is heavier, and is specially employed for high pressures.

SHOOTING: The object of shooting a well is to fracture the gas-bearing rock and allow the gas to pass more freely through the sand to the well proper. The process of shooting consists of exploding a charge of nitroglycerin in the well on a level with the gas vein, and it is necessary that the operator be well versed as to the character of the sand before shooting, as an incorrect explosion is liable to do serious injury to the well.

At the time of drilling it is necessary to take a complete and accurate record of the depth and nature of known sands and formations, and the depth at which oil, gas or water is encountered. With this information a skilled operator can advantageously shoot a well. If the sand is hard, and the well has a capacity under 1,000,000 cubic feet per day, a shot of 80 quarts of nitroglycerin would be correct, whilst a soft sand with the same capacity would require only about 40 quarts. In wells with a flow capacity of more than one million cubic feet per day, it is not advisable to shoot, owing to the danger of lowering the shell into the well. The necessity of careful handling of the charge of nitroglycerin is apparent when its nature and properties are considered.

The composition of *nitroglycerin* is $C_3H_5\,(No._3)_3$, and it is produced by the action of a mixture of sulphuric and nitric acids on glycerol. It is a heavy, oily, and nearly colorless liquid with a specific gravity of 1.6. It possesses the characteristic sweet taste of glycerine, but is dangerously poisonous when taken internally. It is thirteen times as powerful as gunpowder, volume for volume, and produces fourteen thousand times its own volume of gas by detonation. It freezes at 50°F., and must be thawed before lowering into the well for shooting. It is harmless when gently heated, and is thawed to a liquid by placing on a hot plate. The compound is occasionally used in solid form, in which it is changed to a gelatinous substance having a consistency resembling putty or soft rubber. In this form it is slightly more powerful than the liquid. In the liquid form it is shipped in 10-quart cans, whilst the solid is put up in sticks wrapped in paper, and shipped in small boxes. The solid form is safer to handle than the liquid and requires less care in transportation, but is not so easily exploded in the well.

The shell or *torpedo* into which the explosive is charged consists of a tube a few inches in diameter according to the size of the well, and from 2 to 10 feet in length. The shells are anchored to each other by means of a small tin tube soldered on to the point, and adapted to fit over the shell below. The top shell carries a firing head under which is placed a percussion cap.

When using liquid nitroglycerin, the explosion is made by a three edged, elongated piece of cast iron pointed at the end and known as the "go devil." The go-devil weighs about 20 pounds, and it is essential that the material is cast iron so that it is entirely broken up after explosion. With the solid product it is necessary to use a squib of dynamite which is exploded by a fuse. The dynamite is placed in a small tin tube pointed at one end along with a fuse and percussion cap. The fuse is long enough so that the explosion will not take place before reaching the shells in the well.

After the shot has been made, the well is allowed to stand overnight to allow caving in of the sand loosened up after which the well is baled out until the measuring line can be run to the original depth.

TUBING: The tubing which is used to conduct the gas from the well is made of extra heavy pipe capable of resisting high pressures, and is used in sizes from 2 to 6 inches according to the flow capacity of the well. The tubing is anchored to the casing by clamps. On the bottom of the first joint of tubing that is led into the well, a wall packer is connected to prevent the escape of gas. The disc-wall-packer consists of a device with tubing connection at the top and a set of jaws working over a cone and held in place by a spring and cast iron disc. When the packer reaches the location in the well at which it is desirous to set it, a short piece of 3/4 inch pipe is dropped through the tubing which breaks the disc and releases the spring and jaws. The packer will then support the tubing and the anchorage at the surface can be made secure. The first connection above the packer should be made short, and with a right and left hand thread so that if it is desirous to pull out the tubing and the packer is stuck, the whole tubing can be turned on left hand thread and released from the packer.

REMOVING WATER: In the center of the tubing a 3/4 inch siphon is hung, and extends to within one foot of the bottom of the well. The siphon is plugged at the bottom, and the length of piping opposite the gas sand is perforated with 1/4 inch holes spaced one foot apart. When the depth of the well is less than 1,500 feet, or when the gas pressure is very high, the water can be blown out, whilst in deep wells it has to be pumped. When the pumping is necessary, the 3/4 inch suction pipe has to be strengthened at every second or third joint with a cast iron spider which slips over the pipe but not over the coupling. This prevents the pipe for weaving while pumping. The methods and power employed for pumping varies somewhat according to different conditions. In deep wells in isolated districts, a special designed pump is employed in which a horse is used to supply the necessary power, whilst in wells up to 2,500 feet a pumping head is clamped to the tubing and operated by air, gas, steam accordingly.

At a short distance from the top of the well, a drip or receptacle for water is located into which the water can be periodically blown off. The drip is located below the frost line, and the head and tail is of indefinite length according to the amount of water the well is producing.

A view of a completed gas well is shown in Fig. 2, in which the representations are *D* drive pipe, *C* casing, *T* tubing, *S* siphon, *B* blow-off, *L* clamp, and *P* drip.

CLOSING A WELL: The operation of closing a well by a gate valve previous to connecting to the main line is occasionally a difficult matter. When the gas vein is penetrated by the drill, the gas is released and often issues from the well at a very high pressure and ignites. If the anticipated flow is greater than 35,000,000 cubic feet per day, and the conditions are favorable for using the casing as the gas conductor, a gate valve is put on just before drilling into the gas vein, after which it is necessary to reduce the size of the hole. In small wells the gate can be frequently put on with little difficulty by leaving it open until the joint is made.

TESTING THE CAPACITY OF WELLS: The open flow capacity of gas wells is the rate of flow at which the gas is discharged from the well at atmospheric pressure. This rate is considerably greater than the flow under pressure, which is the correct available capacity for distribution for industrial purposes.

The most practical method of obtaining the flow is by the minute pressure test. This is done by first blowing off the well for at least three hours previous to the test, and taking the gauge pressure at the end of one minute after the well has been quickly closed in. From the pressure observation the capacity is computed from the size of tubing, depth of well, and a series of multipliers computed to normal conditions of specific gravity and temperature of the gas.

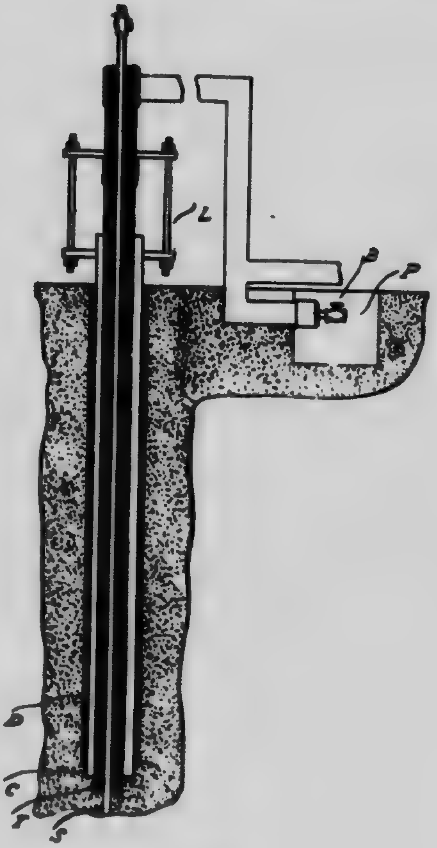

Figure 2

The Table 4 shows the multipliers used up to 300 pounds pressure per square inch, which, when computed with the formula below for capacity of tubing, will give the approximate distributing capacity:

$$C \frac{(D2\times.7854)\ T\times12}{1728}$$

in which:

C = capacity of well tubing, in cubic feet.
D = diameter of tubing in inches.
T = depth of well in feet.

For instance, if the tubing used is 3 inch, and the depth is 2,000 feet, the capacity is

$$C = \frac{(32\times.7854)\ 2000\times12}{1728} = 98.20 \text{ cu. ft.}$$

If the gauge shows a pressure of 150 pounds at the one minute test, the multiplier used is 10.221 as obtained from Table 4, and the capacity of the well is 98.20 ×10.221 = 1003.7 cubic feet per minute, or 60.282 cubic feet per hour.

TABLE 4.
MULTIPLIERS FOR GAS WELL TESTING.

Gauge Pressure in pounds	Multiplier one minute	Gauge Pressure in pounds	Multiplier one minute
2	.190	35	2.372
3	.187	40	2.713
4	.255	45	3.054
5	.324	50	3.395
6	.392	60	4.078
7	.460	70	4.761
8	.529	80	5.443
9	.597	90	6.126
10	.665	100	6.808
11	.733	110	7.491
12	.802	120	8.174
13	.870	130	8.856
14	.938	140	9.539
15	1.006	150	10.221
16	1.075	160	10.904
17	1.143	170	11.587
18	1.211	180	12.269
19	1.279	190	12 952
20	1.348	200	13.624
21	1.416	210	14.317
22	1.484	220	15.000
23	1.552	230	15.682
24	1.621	240	161365
25	1.689	250	17.040
26	1.757	260	17.738
27	1.825	270	18.412
28	1.894	280	19.098
29	1.962	290	19.778
30	2.030	300	20.460

MEASUREMENT IN PIPE LINE: The flow capacity of natural gas is measured on a basis different from artificial gases owing to the different composition and pressures at which it is measured. In the manufacture of artificial gases the pressure at the meter is usually between .15 to .45 pounds according to the downward pressure of the storage holder, whilst the pressure of natural gas occasionally reaches several hundred pounds.

The meters used on natural gas lines may be divided into two classes: (1) The Orifice, (2) The Proportional. The former class operates on the principle of restricting the flow at a given point and creating a differential pressure in relation to it, whilst the proportional meter is adapted to conduct a relative proportion of gas to a positively controlled registering device, from which the correct volume of gas passing through is obtained by computation.

ORIFICE METER: The orifice meter is a widely used instrument for natural gas measurement, and many designs have been introduced with different methods of obtaining the pressures. The orifice plates have been made of hardened steel; soft iron coated with German silver; and mild steel, each of which claim to have their special advantages. The hardened steel plate is based upon the theory that the principle cause of inaccurate measurement is the change in the area of the orifice by sand-blasting and scouring of the hole. The theory of the German silver-coated plate is that the principle danger of the area of the orifice changing is by corrosion. The mild steel is based upon the conclusion that the aforesaid advantages are not as important as having the orifice to exact micrometer dimensions which cannot be obtained with the other materials.

The principle on which the orifice meter depends originated about the year 1750, and was the invention of the French physicist, Henri *Pitot*, The invention was originally used to measure the velocity in streams of water. In the original form it consisted of a bent tube, the mouth of which is pointed up stream and measures the dynamic pressure of the stream by the head produced in the vertical part of the tube.

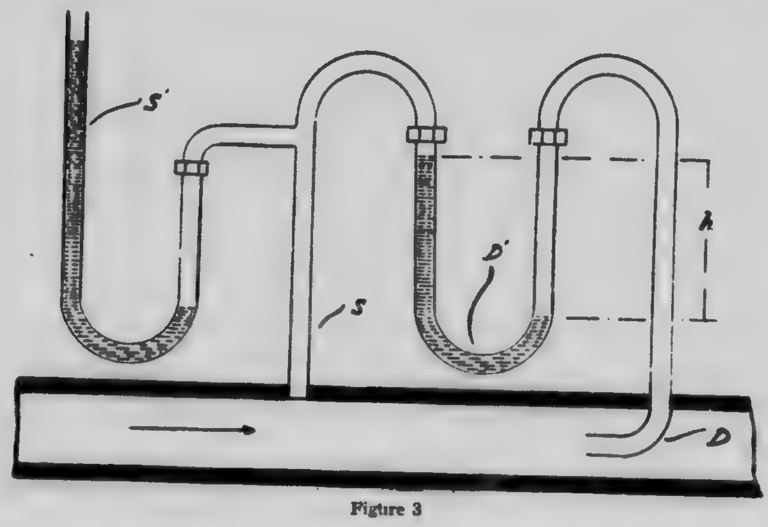

Figure 3

The invention was first modiified for the measurement of natural gas by adding a second tube to measure the static or gauge pressure. This is illustrated in Fig. 3, in which D is a piece of pipe or tubing inserted in the gas main so that its open end is directly in the center of the main, and in a position opposite the flow of gas. The pipe S is located at a distance of one foot from D on the upstream side, and conducts the static pressure to U-tube S' and the opposite side of tube D'. Under these conditions the pressure on one side of D' is static, whilst on the other side it is static +dynamic, the latter of which is measured by the height of the column h. It is evident then that the height of the water h is equal to the pressure which would produce the velocity of gas flowing in the main.

In order to standardize the Pitot tube for gas measurement, the gas was passed to a holder of known capacity under various conditions of flow and pressure. By this, data was obtained as to the volume of gases passed through in a definite time under different conditions from which co-efficients were obtained, and standard tubes made in two, three, four and five inch sizes.

The Pitot tube can be used to advantage in testing the open flow of wells, determining line leakage, and testing meters. The simplicity of this instrument makes it portable, and easily installed in a pipe line, but its accuracy is liable to be disturbed owing to the interior surface of the pipe being rough and uneven, a condition which is common in commercial piping. The range of measurement is also limited, and for accurate work it is not practical to have a range higher than 4 to 1, or 100.000 to 25.000, with a minimum dfferential pressure of 2.25 inches of water.

The orifice meter is a development of the Pitot tube, and consists of a thin plate in which there is an orifice machined to accurate dimensions. The static pressure is obtained on the up-stream side of the orifice flange by an ordinary recording pressure gauge, and the differential pressure is obtained from the down-stream side by a specially constructed differential gauge.

In computing the volume of gas passed through the orifice meter, the average temperature and specific gravity of the gas have considerable effect on the accuracy of the meter, and the co-efficient used in computation must be corrected to the conditions. In considering the installation of these meters, it is necessary to know the maximum and minimum pressures and volumes so that the correct size meter can be installed and operated within a range suitable for the conditions.

An improved development of the orifice meter is that known commercially as the Venturi. The Venturi meter is designed to operate on the same principle as the former, and has a further advantage in that the meter tube is made in the shape of a cone so that the restricted area from the Inlet of the tube to the throat or orifice is gradual, whilst in the original orifice is in a flat plate, and the differential pressure is created suddenly.

PROPORTIONAL METER: The proportional meter is specially suitable for measuring gas in large volumes, or when the pressure exceeds five pounds. The meter works on the principle of conducting a definite proportion of the flow to actuating and recording mechanism, from which the actual flow is obtained by computation. The accuracy of the meter depends largely on maintaining an unrestricted flow through the ports and passageways leading through the proportional chambers, and this can only be affected by periodically cleaning the meter. At the inlet of the proportional chambers there is provided a sponge chamber, as seen at *S*, Fig. 4, to screen off the solid matter, and largely prevent deposits in the meter proper. In testing a meter the gas should be measured at 4 or 8 ounce pressure, from which the actual measurement is computed by multipliers when the pressure is greater. The correct proportion is obtained by means of valves V and V′ which actuate together and are closed and opened in relation to each other.

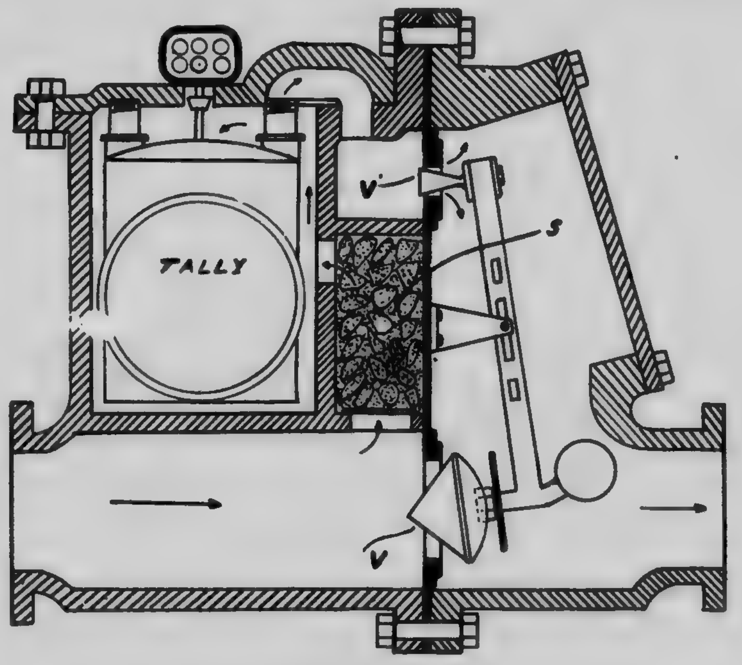

Figure 4

BASIS OF MEASUREMENT: The four-ounce basis of measurement is most commonly used, and the multipliers for higher pressures are obtained from this base. The multipliers originate from BOYLE'S LAW OF GAS DENSITIES which is "*The volume of gases varies inversely as to the pressure,*" and the formula for obtaining a multiplier for certain conditions of pressure is

$$M = \frac{G+A}{A+.25}$$

in which M = Multiplier.

G = Gauge pressure in pounds.

A = Atmospheric pressure at 14.4 pounds.

.25 = Basis of measurement, or 4-ounce.

Assuming that the gauge pressure of the line is 20 pounds, the multiplier will be

$$\frac{20+14.4}{14.65} = 2.3481,$$

and this multiplied by the meter reading gives the volume of gas passed through at standard or four-ounce pressure.

In Table 5 below, a range of multipliers is given from standard pressure to 350 pounds.

TABLE 5.

PRESSURE MULTIPLIERS FOR GAS MEASUREMENT from 4-OUNCES.

Pounds per Square inch.	Multiplier	Pounds per Square Inch	Multiplier
.25	1.00000	83.50	6.68259
.50	1.01706	84.00	6.71672
1.00	1.05119	84.50	6.75085
1.50	1.08532	85.00	6.78498
2.00	1.11945	85.50	6.81911
2.50	1.15358	86.00	6.85324
3.00	1.18771	86.50	6.88737
3.50	1.22184	87.00	6.92150
4.00	2.55970	87.50	6.95563
4.50	1.29010	88.00	6.98976
5.00	1.32423	88.50	7.02389
5.50	1.35836	89.00	7.05802
6.00	1.392449	89.50	7.09215
6.50	1.42662	90.00	7.12627
7.00	1.46075	90.50	7.16040
7.50	1.48488	91.00	7.19453
8.00	1.52901	91.50	7.22866
8.50	1.56313	92.00	7.26279
9.00	1.59726	92.50	7.29692
9.50	1.63139	93.00	7.33105
10.00	1.66552	93.50	7.36518
10.50	1.69965	94.00	7.39931
11.00	1.73378	94.50	7.43443
11.50	1.76791	95.00	7.46757
12.00	1.80204	95.50	7.50170
12.50	1.83617	96.00	7.53583
13.00	1.87030	96.50	7.56996
13.50	1.90443	97.00	7.60409
14.00	1.93856	97.50	7.63822
14.50	1.97269	98.00	7.67235
15.00	2.00682	98.50	7.70648
15.50	2.04095	99.00	7.74061
16.00	2.07506	99.50	7.77474
16.50	2.10921	100.00	7.80887
17.00	2.14334	101.00	7.87713
17.50	2.17747	102.00	7.94539
18.00	2.21160	103.00	8.01365
18.50	2.24573	104.00	8.08191
19.00	2.27986	105.00	8.15107
19.50	2.31399	106.00	8.21843
20.00	2.34812	107.00	8.28668
20.50	2.38335	108.00	8.35494
21.00	2.41638	109.00	8.42320
21.50	2.45051	110.00	8.49146
22.00	2.48464	111.00	8.55872
22.50	2.51877	112.00	8.62798
23.00	2.55290	113.00	8.69624
23.50	2.58703	114.00	8.76450
24.00	2.62116	115.00	8.83276
24.50	2.65528	116.00	8.90102
25.00	2.68941	117.00	8.96928
25.50	2.72354	118.00	9.03745
26.00	2.75767	119.00	9.10580
26.50	2.79180	120.00	9.17406
27.00	2.82593	121.00	9.24232
27.50	2.86006	122.00	9.31058
28.00	2.89419	123.00	9.37883
28.50	2.92832	124.00	9.44709
29.00	2.96245	125.00	9.51535
29.50	2.99658	126.00	9.58361
30.00	3.03071	127.00	9.65187
30.50	3.06484	128.00	9.72013
31.00	3.09879	129.00	9.78839
31.50	3.13310	130.00	9.95665
32.00	3.16723	131.00	9.92491
32.50	3.20136	132 00	9.99317
33.00	3.23549	133.00	10.06143
33.50	3.26942	134.00	10.12969

TABLE 5—*Continued.*

PRESSURE MULTIPLIERS FOR GAS MEASUREMENT from 4-OUNCES.

Pounds per Square inch.	Multiplier	Pounds per Square Inch	Multiplier
34.00	3.30375	135.00	10.19795
34.50	3.33788	136.00	10.26621
35.00	3.37201	137.00	10.33447
35.50	3.40614	138.00	10.70273
36.00	3.44027	139.00	10.47098
36.50	3.47440	140.00	10.53924
37.00	3.50853	141.00	10.60750
37.50	3.54266	142.00	10.67576
38.00	3.57679	143.00	10.74402
38.50	3.61092	144.00	10.81228
39.00	3.64505	145.90	10.88951
39.50	3.67918	146.00	10.94880
40.00	3.71331	147.00	11.01706
40.50	3.74744	148.00	11.08532
41.00	3.78156	149.00	11.15338
41.50	3.81569	150.00	11.22184
42.00	3.84982	151.00	11.29010
42.50	3.88395	152.00	11.35836
43.00	3.91808	153.00	11.42662
43.50	3.95221	154.00	11.49488
44.00	3.98634	155.00	11.56313
44.50	4.02047	156.00	11.63139
45.00	4.05460	157.00	11.69965
45.50	4.08873	158.00	11.76791
46.00	4.12286	159.00	11.83617
46.50	4.15699	160.00	11.90443
47.00	4.19112	161.00	11.97269
47.50	4.22525	162.00	12.04095
48.00	4.25938	163.00	12.10921
48.50	4.29351	164.00	12.17747
49.00	4.32764	165.00	12.24573
49.50	4.36177	166.00	12.31392
50.00	4.39590	167.00	12.38225
50.50	4.43003	168.00	12.45051
51.00	4.46416	169.00	12.51377
51.50	4.49829	170.00	12.58703
52.00	4.53242	171.00	12.65529
52.50	4.6655	172.00	12.72354
53.00	4.60608	173.00	12.70180
53.50	4.63481	174.00	12.86006
54.00	4.66894	175.00	12.92832
55.00	4.73720	176.00	12.99658
55.50	4.77133	177.00	13.06484
56.00	4.80546	178.00	13.13310
56.50	4.83959	179.00	13.20136
57.00	4.87372	180.00	13.26932
57.50	4.90784	181.00	13.33788
58.00	4.94197	182.00	13.40614
58.50	4.97610	183.00	13.47440
59.00	5.01023	184.00	13.54266
59.50	5.04436	185.00	13.61902
60.00	5.07849	186.00	13.67918
60.50	5.11262	187.00	13.74744
61.00	5.14675	188.00	13.81569
61.50	5.18088	189.00	13.88395
62.00	5.21501	190.00	13.95221
62.50	5.24914	191.00	14.02047
63.00	5.28327	192.00	14.08873
63.50	5.31740	193.00	14.15699
64.00	5.35153	194.00	14.22525
64.50	5.38566	195.00	14.29351
65.00	5.41979	196.00	14.36177
65.50	5.45392	197.00	14.43003
66.00	5.48805	198.00	14.49829
66.50	5.52218	199.00	14.56655
67.00	5.55631	200.00	14.63481
67.50	5.59044	204.00	14.90784
68.00	5.62457	208.00	15.18088
68.50	5.65870	212.00	15.45392
69.00	5.69283	216.00	15.72696
69.50	5.72696	220.00	16.00000
70.00	5.76109	224.00	16.27203

TABLE 5—*Continued.*

PRESSURE MULTIPLIERS FOR GAS MEASUREMENT from 4-OUNCES.

Pounds per Square inch.	Multiplier	Pounds per Square Inch	Multiplier
70.50	5.79522	228.00	16.54607
71.00	5.82935	232.00	16.81911
71.50	5.86348	236.00	17.09215
72.00	5.89761	240.00	17.36518
72.50	5.93174	245.00	17.70648
73.00	5.96587	250.00	18.04778
73.50	6.00000	155.00	18.39807
74.00	6.03412	260.00	18.73037
74.50	6.06825	265.00	19.07167
75.00	6.10238	270.00	19.41296
75.50	6.13651	275.00	19.75427
76.00	6.17064	280.00	20.09556
76.50	6.20477	285.00	20.43685
77.00	6.23890	290.00	20.77815
77.50	6.27303	295.00	21.11945
78.00	6.30716	300.00	21.46075
78.50	6.34129	305.00	21.80224
79.00	6.37524	310.00	22.14334
79.50	6.40955	315.00	22.48464
80.00	6.44368	320.00	22.82593
80.50	6.47781	325.00	23.16723
81.00	6.51194	330.00	23.50853
81.50	6.54607	335.00	23.84932
82.00	6.58020	340.00	24.19112
82.50	6.61433	345.00	24.53242
83.00	6.64846	350.00	24.87371

COMPRESSION: The location of gas wells is often 100 miles or more from the point at which the gas is needed as fuel, and when such is the case it is generally necessary to operate a compression station near the wells. When the rock or natural pressure is high, and the point of consumption is only a few miles from the field, the compression plant is not necessary. In most cases, however, it is more economical to compress the gas to a high pressure as the size of the pipe line can be reduced accordingly, and this eliminates a great expenditure when the line is 50 miles or more in length. It is estimated that a 6-inch pipe line operated at 300 pound pressure at the compressors would deliver 3,000,000 cubic feet per 24 hours at a point 100 miles distant and discharge pressure of 5 pounds, whilst to deliver the same volume of gas the same distance with a natural or rock pressure of 14 pounds at the wells, it would require an 18 inch line, or 10 to 12 times the expenditure.

The design and location of compressors vary somewhat with the conditions, and they may be driven either by gas, steam, or electric motors of the induction type. The compression outfit is designed also to quickly lower the temperature and cause condensible matter to be brought down. The lowering of the temperature simultaneously causes a contraction in the volume of the gases which proportionately increases the flow from the wells. It is advisable in most cases to adopt a two-stage system of compression, and to pass the gas through a cooler before entering the second stage. The general arrangement of a compression plant is illustrated in Figs. 5 and 6.

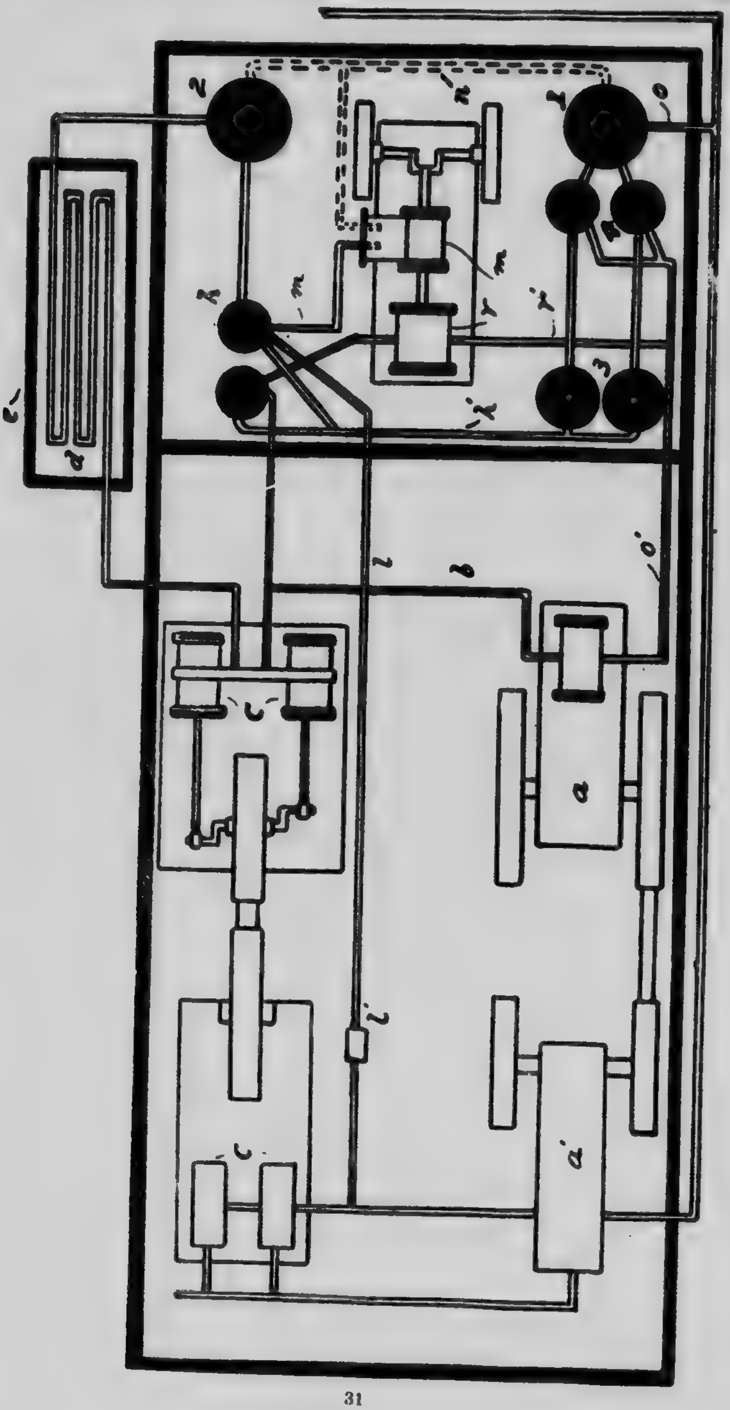

Figure 5

Referring to Fig. 5, a vacuum pump *a*, operated by motor *a'* affects a certain degree of compression in the pipe *b* which leads to the main compression pumps *c*, driven by gas engine *e'*. The compressed gases flowing from pumps *c* are passed through a cooler which consists of a coil *d* arranged in a tank *e* through which water is caused to pass to absorb the heat of compression. When the gases leave the coil *d* they are passed through a coil *f*, Fig 6, which is arranged in shell *g* connected by piping to a cold fluid supply. The coil *f* of the refrigerator is connected to separating tank *h* in which collects the condensible vapors, and allows them to be carried off through piping *h'* to storage tank 3, Fig. 5.

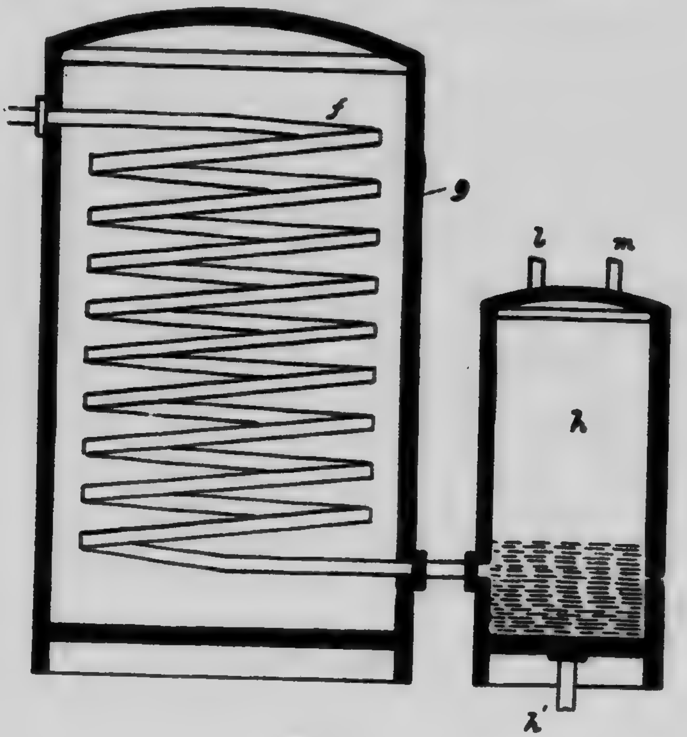

Figure 6

A portion of the permanent gases from tank *h* passes off through pipe *i* and reducing valve *i'* for use in the gas engine, and the remainder passes off through pipe *m* for expansion. It may here be stated that whilst the compression of gases generates heat, the expansion of compressed gases will act adversely and thereby affect a lowering of the temperature, and if the expansive force is utilized in the performance of work, the reduction of the temperature is considerably greater. It is obvious, then, that by conducting compressed gases through the refrigerator the heat generated at the point of compression is absorbed and condensible vapors extracted; also that by conducting the gases from the separator *h* to engine *m'* through piping *m*, the hitherto compressed gases are expanded in the performance of work, by which the greatest lowering of temperature is affected. The expanded gases are exhausted through pipe n to the shells of the refrigerators 1 and 2 as a cooling fluid for other gases passing through the refrigerator.

The coil f of the refrigerator 1 is connected at one end of the line of pipe o leading from one or more wells, whilst the opposite end of the coil is connected to the pump a through collecting drums 4, which are operated alternately to fill one or the other of storage tanks 3. The engine m' is employed to operate pump r which delivers gas under pressure to compression pumps e, and is connected at its inlet by pipe r' to line e' on the delivery side of refrigerator 1.

PURIFICATION: At various points on the line it is frequently necessary to pass the gas through some form of separator or purifier to remove sand or other solid matter or condensable vapors. The class of purifier used may be of varied design, and one of the most effective is a combination of apparatus illustrated in Fig. 7.

In the illustration a is the gas supply which is connected to the wells or pipe line, and is provided with a pressure reducing valve or regulator a' adapted to throttle the flow of gas transversing the line a and lower the pressure to a desired point.

The throttling of the gases at this stage produces a forced expansion of the gases and condensable vapors, and simultaneously lowers the temperature in proportion thereof. The fall in temperature and pressure causes the entrained vapors to condense to a liquid, and to collect this condesnable matter, the gases are caused to discharge into the separator b through nozzle c. The inlet c' is located in the casing d, and the nozzle is turned downwards so that the gases are discharged immediately above the recrement e. The discharge end of the nozzle is slightly convergent so that the gases issuing therefrom are directed downwardly in a concentrated stream towards the port e.

At the top of the casing d a gas delivery port f is provided from which the gases are conducted to distribution mains g, and a series of baffles i project partially across the separator chamber to provide an extended contact surface on which moisture collects.

The discharge port e is located at the lowest part of the casing, and is connected by a short pipe h to a resorvoir j which collects the impurities. The pipe section h is axially aligned with the delivery end of the nozzle c, and the inertia of the impurities as they issue from the nozzle causes them to continue their downward course, and be deposited in the reservoir j, whilst the permanent gases momentarily come to rest within the casing d and then reverse the direction of flow, and proceed towards the distribution main.

The reservoir j is made comparatively large to enable it to receive large quantities of water vapor which are liable to be delivered at certain times. When water is encountered in the wells in large quantities, it is invariably delivered through the field lines as headers or waves, and to efficiently accommodate these headers, the reservoir is made larger than is required under normal conditions, so that the normal operation of the separator is not interfered with when the waves of water appear.

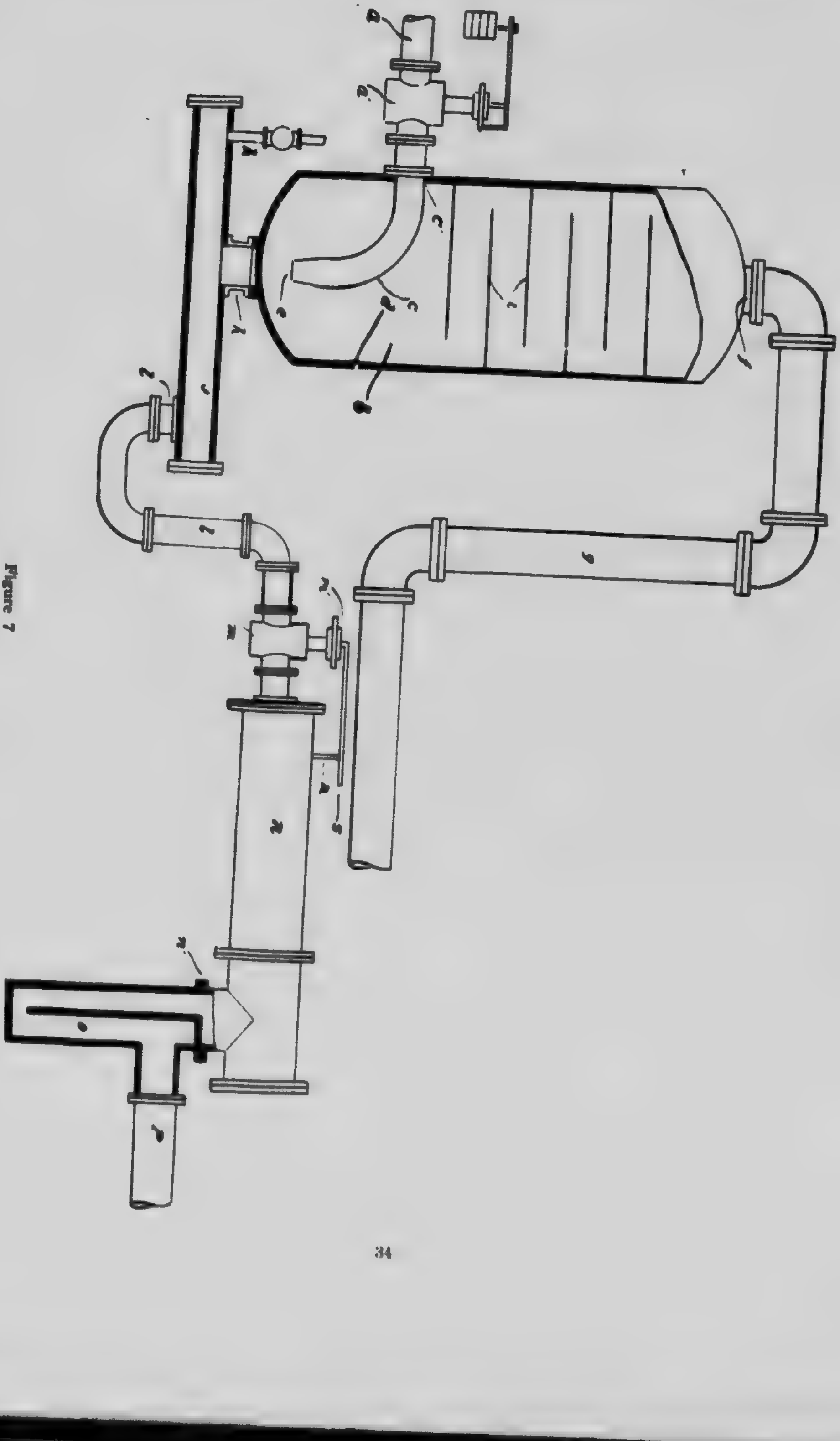

Figure 7

It is frequently desirable to flush the reservoir with liquid other than that received from the chamber b, for which purpose a supply k is provided. A recrement discharge port is provided at L. and is connected by a pipe L' to pressure regulator m, which communicates with a second reservoir n. This reservoir is located at a level above that of j, since the latter is ordinarily located so far below the surface of the earth that it would be impractical to drain the reservoir n if it were on the same level. The reservoir n is provided with a discharge port n' which is in communication with one leg of a trap o, of which the other leg communicates with the discharge pipe p, which conducts the condensed matter off. The trap o is of sufficient depth to seal the gases from the atmosphere.

The type of regulator m is that provided with an operating diaphragm which is located in the pressure chamber m', the upper portion of which is in communication with reservoir n by means of pipe r. The said pipe is provided with a restricted discharge port s, which is controlled by a needle valve, and through which gas delivered to the reservoir with water is discharged. As long as liquid is discharged from the reservoir j through the pipe L' the regulator will remain open, as the water delivered will exert no back pressure in the latter reservoir, and consequently will not actuate the diaphragm contained within the chamber m'. When gas is delivered through the regulator, the pressure in the reservoir n increases and a back pressure is exerted upon the actuating diaphragm of the regulator by way of pipe r, which tends to close it, and cuts off communication between reservoirs J and n. This arrangement has the effect of limiting the waste of gas to relatively small quantities, which discharge through needle valve to port s. When the gas pressure within the reservoir n decreases, the regulator again opens and remains so while ever a continuous flow of liquid is delivered through the piping L'.

LOW-PRESSURE SERVICE: At the borders of a city or industry where the natural gas is used as fuel, it is necessary to reduce the pressure down to about 4 or 6 ounces as a preventive against fire from burner devices, and to insure uniform service.

For this purpose a regulator or reducing valve is installed in the line, and is controlled by weights on a lever arm connecting with a diaphragm and valve stem. These regulators are divided into the three classes: HIGH, INTERMEDIATE and LOW-PRESSURE. The first class are employed to take care of pressures from 500 to 600 pounds and lower to 50 or 100 pounds; the second class will lower the pressure from 50 or 100 to 15 or 20 pouuds; and the low-pressure regulator will lower to a few ounces. The high pressures are usually brought down at some distance from the point of consumption in conjunction with purifying apparatus, and the low-pressure regulator is frequently the only one which it is necessary to employ in the city.

These regulators should not be placed in a ground pit but in a small house or room where they are easily accessible and at a more regular temperature. At a distance of 50 feet on the low-pressure side, a connection is made for a low-pressure recording gauge, and the regulator should be fitted with a by-pass connection to enable inspection or repair without stopping the gas service. The general arrangement of connections is shown in Fig. 8. At a point near the regulator on the low-pressure side, a safety seal of oil or salt water should be placed as a preventive against the regulator failing to reduce the pressure, and allowing excess pressure to pass to the low-pressure system. This consists of a small tank into which a connection from the low-pressure is led and sealed in the liquid to a depth at which it will hold the normal pressure and break when the limit is reached and allow the excess to pass to the atmosphere.

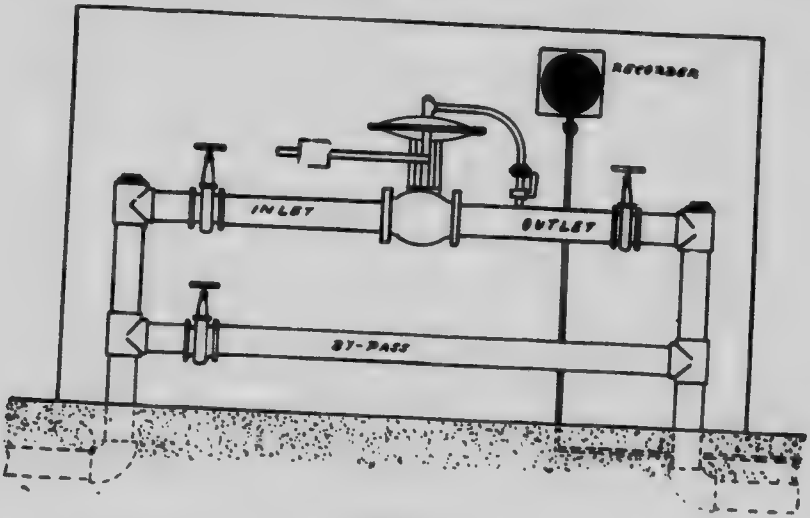

Figure 8

The composition of natural gas is chiefly CH_4 *methane* and *ethane* C_2H_6, and usually contains very little impure gases. In some fields, however, the gas contains a high percentage of hydrogen sulphide which has little heat value; is very poisonous and possesses a very disagreeable odor, and is consequently an undesirable compound. This gas may be removed by installing a small tank at the inlet of the meter and charging it with rusted iron borings mixed with shavings for porosity. On passing through this material, the oxygen of the iron is taken up by the hydrogen of the sulphide and brought down as water H_2O, whilst the sulphur combines with the metallic iron as ferrous sulphide. On cleaning out the purifier periodically and exposing the material to the air, the iron is re-oxidized and the sulphur liberated, which enables it to be used over again.

HISTORY OF COAL GAS: The generation of inflammable gases by the destructive distillation of coal or other carbon containing matter was discovered in the latter part of the seventeenth century, but it was not until about 100 years later that the discovery was utilized for the manufacture of gases on a commercial scale. The exact date of this development is a subject of much discussion, and the first process to have been patented appears to have been by Philippe Lebon in 1799. A few years previous to this date, however, William Murdock had done some experimenting, and in 1802 he lighted the Soho Engine Works by gas obtained from coal, which in the writer's belief is the first practical development.

In the year 1812 the first company was chartered for the supply of gas for illuminating purposes, by the London & Westminster Gas Light and Coke Company, after which the process slowly developed with improved apparatus until the year 1835, when it had been adopted in seven or eight of the most important towns.

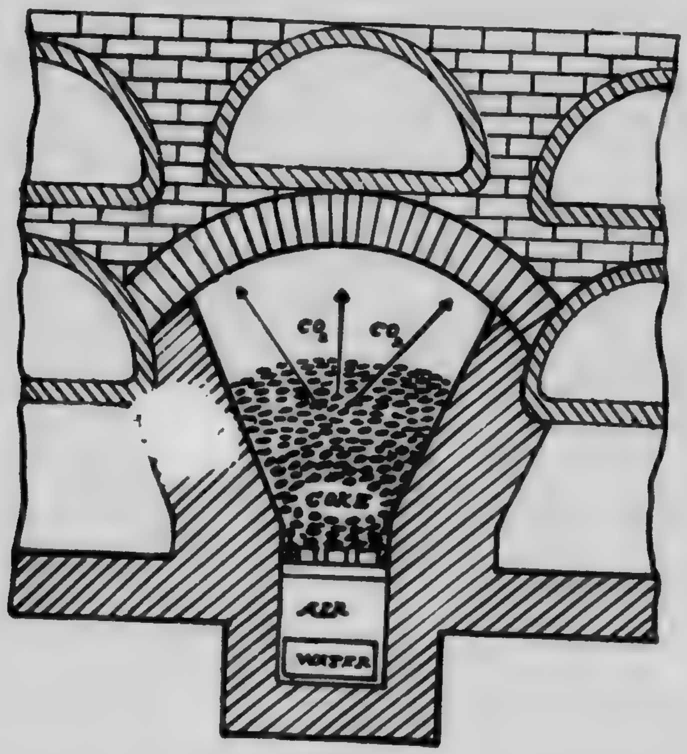

Figure 9

The present-day practice of carbonization consists of heating the coal in a closed chamber or *retort* which is made of fireclay. These retorts are made in various shapes and sizes, and are placed in a series of from three to nine in firebrick settings which are transversed by a series of flues, which serve to conduct the heat given off from a producer arranged in a central position beneath the retorts. The arrangement of these flues for the purpose of obtaining the maximum amount of heat has been a subject of wide variation, and different builders of retort settings invariably have some slight different arrangement from which some advantage is claimed.

DIRECT AND REGENERATIVE FIRING: Until the latter part of the nineteenth century the retort settings were direct fired, but in recent years this method has been almost universally abandoned for the gaseous or regenerative firing, which has proven to be more economical. In the direct fired setting, the theory of control is to provide a shallow bed of fuel (usually coke), and a full supply of air beneath the grate, which enables the carbon of the coke to combine with two atomic proportions of oxygen and produce carbon dioxide direct within the furnace. The product of combustion then passes into flues around the retorts, which raises the temperature of the retort to a degree at which volatile matter will be distilled off. In this class of setting the number of retorts capable of being heated by one producer is generally from three to five, and the path of the burning gases is as seen in Figs. 9 and 10. The direct fired furnace is so called in view of the fact that complete combustion takes place direct within the furnace and thereby heats the retorts by the first law of combustion.

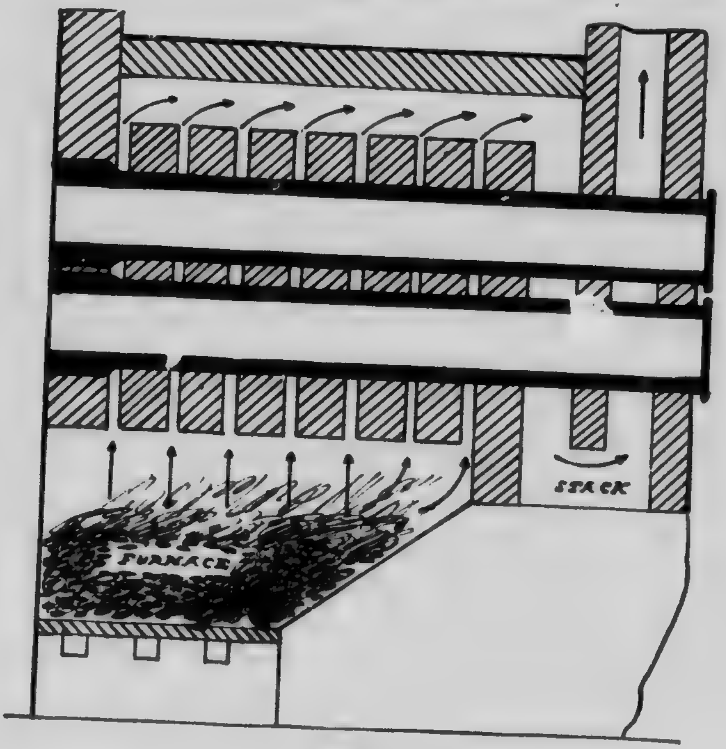

Figure 10

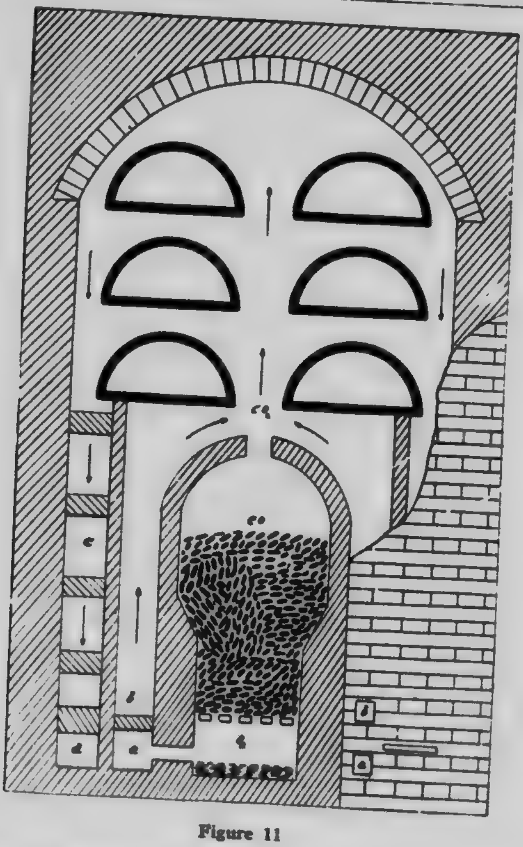

Figure 11

The regenerative or producer furnace has practically superceded the former and is so called owing to it producing or regenerating gases which may be conducted to combustion chambers adjacent to the retorts for the subsequent evolution of heat therein. In this type of furnace(Figs. 11 and 12) a deep bed of fuel is provided, the object of which is to saturate the burning carbon dioxide produced in the lower part of the fire with another atomic proportion of carbon, so that the gases arising from the top of the fuel bed consist chiefly of carbon monoxide from which secondary combustion can be produced at the point desired. Referring to Fig. 11, the primary air enters beneath the grate bars at *a*, and the excess of oxygen produces complete combustion of the carbon in the lower part of the bed to CO_2. The carbon dioxide formed passes up to fuel, and the gas in the presence of an excess of carbon is reduced to CO. This gas is then conducted to combustion chambers arranged within the setting, where it is met by secondary air, and is reburned as carbon dioxide and distributed through flues adjacent to the retorts. The secondary air enters the setting at *b*, whilst the products of combustion are passed down flues *c* to chimney *d*. This arrangement raises the temperature of the secondary air to about1,800°F., and on meeting the burning gases from the producer at *e* a vigorous combustion takes place. Briefly, the advantages of the regenerative over the direct fired furnace are:

(1) It effects considerable saving in producer fuel.

(2) It provides a more uniform heat on the surface of the retorts.

(3) It effects a saving of labor per unit of gas made, by enabling more retorts to be heated from one producer.

(4) It lengthens the life of the retorts by more uniform distribution of heat.

(5) It enables the temperature of the retorts to be kept under better control and increases the make per unit of coal carbonized.

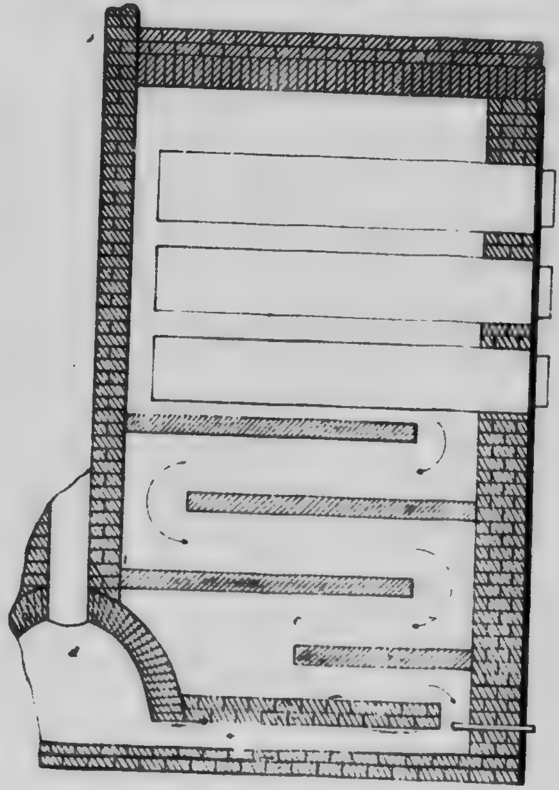

Figure 12

RETORTS: The materials employed for the construction of retorts is generally fireclay or iron, and the shape and sizes of these may vary somewhat as to the nature of fuel to be carbonized, and operating conditions of the setting. The theoretical considerations to be kept in view in deciding upon the shape and size of horizontal retorts may briefly be stated as follows:

(1) It should allow for the charge of coal being placed in a thin even, layer.

(2) It should avoid unnecessary space between the top of the coal and hot crown of the retort.

(3) It should be such that the distribution of heat is uniform throughout the entire surface, and thereby enable the heat to uniformly penetrate the layer of coal in the interior.

The most common design of retorts are the *round*, the *oval*, and the *semicircle*. The round retort is claimed to be the most durable, and also has the advantage of being the easiest to draw. It is usually made about 16 inches in diameter. The oval retort is made in sizes about 15 to 20 inches in cross section, and comes next to the round retort with regards to durability. The *semicircle* is made about 14 to 21 inches, and is the most economical in the distribution of heat, and also allows the coal to be placed in a thin even layer. The dimensions of the retorts also vary with regards to their length, and on the average are about 9 feet long when made in one piece, or 18 feet when they are provided with two mouthpieces, and pass through the entire breadth of the setting. These retorts are set in groups of from five to nine around the producer, and each group constitutes what is known as a *bench*. The number of benches placed side by side are usually in accordance with the daily output of the words, and each group constitutes a *stack*.

In order to illustrate this more clearly, it may be assumed that the retort house contains two stacks, each of which comprise eight benches of nine retorts; which makes the total number of retorts as 2×8×9=144. Of these it is practical to allow one-third being down for emergency or repair, which makes the total number in operation as approximately 100. The amount of gas capable of being produced from one retort varies with the qaulity of the coal and working temperatures, and the capacity of each charge. Assuming that each retort takes a charge of 1,500 pounds of coal per 24 hours, the amount of coal carbonized in 100 retorts is 150,000 pounds, and on taking the volume of gas produced per pound as 5 cubic feet, the output of the plant is 150,000 ×5=750,000 cubic feet per 24 hours.

The walls of the retorts *a* Fig. 13, are from two to three inches in thickness with a heavier portion at the front end which constitutes a collar to which a *mouthpiece* is securely fastened. The mouthpiece *b* consists of a heavy iron casting that carries a door which is opened during the charging and drawing periods. At the top of the mouthpiece an opening is provided which conducts the gas to an ascencion pipe, through the saddle pipe *c*, the dip pipe *d*, into the hydraulic main *e*. The hydraulic main is usually made of wrought iron or mild steel, and extends the whole length of the bench, and is supported on joist *f* so that it is sufficiently removed from the heat of the setting to prevent the tarry matter in the bottom of the main from pitching, and also to maintain a perfect level so that tar will flow to a well, and simultaneously insure the dip pipe having a constant liquid seal. The hydraulic main and dip pipe together form an automatic valve which enables the gas to pass off from the retorts and at the same time prevents it from returning when the retorts are opened during the charging and drawing periods. The gases entering the main contain a large amount of tar and ammoniacal vapors, which are condensed by the liquid and deposited in the main, of which the tar sinks to the bottom by reason of its gravity.

In recent years the design and construction of retorts have been a subject of great importance, and the arrangement of the setting demands that the greatest care and skill be exercised to insure satisfactory and efficient operation. The first important factor is to provide a good foundation, and the thickness of the concrete may vary somewhat according to the previous nature of the ground. Under average conditions it will be necessary to lay about 18 to 20 inches of concrete where the ground is firm and dry, and it may be necessary to increase this to 3 feet with metal reinforcements when the sub-strata is saturated with moisture. It is advisable to put a good class of material in the foundation, as unusual stresses are brought down upon it by uncertain expansion of the setting, and it is also advisable to lay the concrete in layers over the whole area of foundation at one time if possible; otherwise the edge of an incomplete layer should be chipped to prevent a crack where the concrete joins.

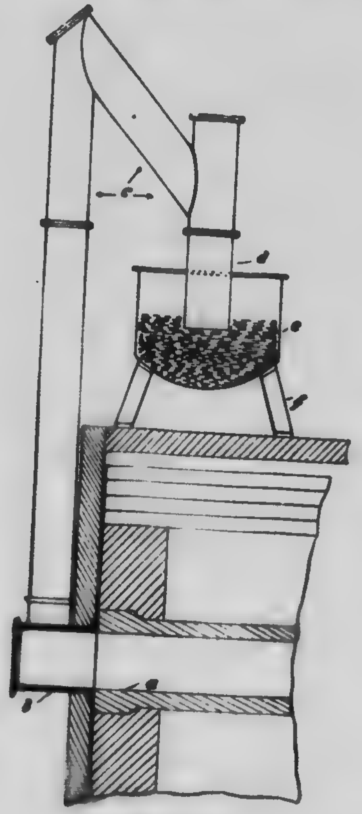

Figure 13

The main flue and chimney, however, is common to all classes of retorts, and if they are of the horizontal or inclined class, the clinkering floor is generally on the ground level, whilst the charging and withdrawing floors are elevated. The setting is built of firebricks cemented together by fireclay, which is a hydrated compossition of silica and alumina, with a small percentage of oxide of iron, magnesia, potash, or soda. In present-day practice the horizontal retorts are being largely substituted by the inclined class, Fig. 14, in which the fuel is charged and discharged by gravity.

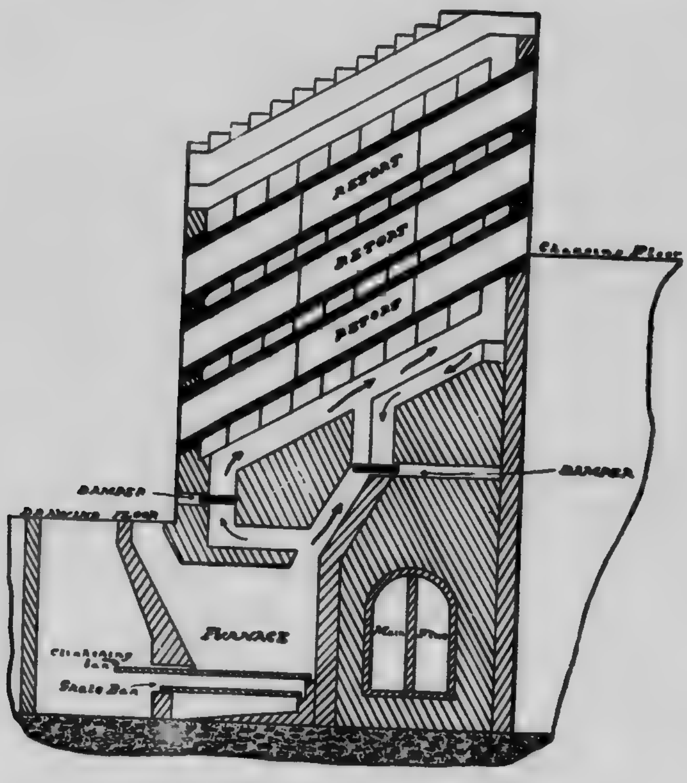

Figure 14

TEMPERATURE CONDITIONS: The most important factor in the economical operation of a bench of retorts is the maintenance of regular heats around them. This is controlled from the producer and air dampers, and the most important points to be observed are:

(1) To regulate the primary air so that the maximum amount of combustible gas is given off from the top of the producer.

(2) To keep the fuel bed in the producer at a uniform depth.

(3) To admit only sufficient secondary air as will burn the gases produced.

(4) To frequently remove clinker from the fire and keep such in a healthy condition.

(5) To keep a supply of water in the drip pan beneath the grate of the producer and thereby keep the lower part of the fuel bed from being overheated.

The fuel used in the producer is usually coke, and the amount used per ton of coal carbonized may vary from 15 to 30 per cent. according to good or bad practice. The best results are undoubtedly obtained by careful attention to the producer fire and the lower part should be periodically pricked to prevent clinker accumulating in large masses, and smaller particles of clinker drawn by means of hooks. At least once in 24 hours the fire should be thoroughly cleaned and this should proceed by opening the ash doors, and driving pointed iron bars into the bed of fuel above the clinker level. These bars constitute a temporary grate which serves to support the fuel and enable the permanent grate to be removed. The solid clinker is then removed by long chisels and hooks, after which the grate is put back to its position and the bars which constitute the temporary grate withdrawn.

In some benches an instrument is provided which records the percentage of CO_2 in the flue gases, and by careful observation to this, the supply of primary and secondary air can be adjusted to effect complete combustion within the setting, and simultaneously avoid the risk of admitting too much secondary, and thereby cooling the setting.

In order to ascertain the temperature of the bench, it is usual to employ some form of pyrometer. In many plants this is of the thermo-electric type, which depend for their action on the fact that when two metals are heated in contact, and the cool end connected by wire an electric current is generated in proportion to the temperature to which the contact is heated. The metals usually employed are platinum and platinum rodium, which are fused together at one end and connected at the other end to a suitable indicating gauge. In some plants these applicances are substituted by some form of pyrometric cone, of which the *Seger* is the most common. These cones have been claimed to be more accurate and economical, and consist of fusible pyramid-shaped objects of vitreous matter. They are made in a series indicated by a number, each of which have a definite melting point which corresponds to a scale prepared by the inventor. The cones are made in a series adapted to melt at about 40 different temperatures, but for practical purposes the series given below will be usually sufficient.

TABLE 6.

MELTING POINT OF SEGER CONES.

Cone No.	Melting Point	Cone No.	Melting Point
.010	1742 Deg. F.	6	2282 Deg. F.
.09	1788 "	7	2318 "
.08	1814 "	8	2354 "
.07	1850 "	9	2390 "
.06	1886 "	10	2426 "
.05	1922 "	11	2462 "
.04	1958 "	12	2498 "
.03	1994 "	13	2534 "
.02	2030 "	14	2570 "
.01	2066 "	15	2606 "
1	2102 "	16	2642 "
2	2138 "	17	2678 "
3	2174 "	18	2714 "
4	2210 "	19	2750 "
5	2246 "	20	2786 "

Another simple form of pyrometer which is frequently used in the absence of cones or indicating apparatus, is to place a small block of wrought iron into a retort until its temperature is equivalent to that of the latter, after which it is removed and immersed into a known weight of water, the temperature of which has been previously taken. The temperature of the water after immersion of the heated iron is then taken and the retort temperature calculated from the formula.

$$T_2 = \frac{T_1 + W(T_1 - T)}{SW_1}$$

in which T = Temperature of water before immersion.

T_1 = Temperature of water after immersion

W = Weight of water in pounds.

W_1 = Weight of iron in pounds.

S = Specific heat of wrought iron .113.

for instance, if

T_1 = 200 degrees F. T = 50 degrees F.

W = 100 pounds. W_1 = 200 pounds.

the temperature of the retort will be

$$\frac{200 + 100\ (200 - 50)}{.113 \times 200} = \frac{45.000}{22.6} = 1990F.$$

Irrespective of the aforesaid methods of temperature calculation, the experienced gas engineer can usually make a very close judge at the approximate temperature by color indication. The heat of the setting becomes visible at about 900°F from which it deepens in accordance with the following table:

TABLE 7

RETORT TEMPERATURES.

Color	Temp.	Color	Temp.
Dull Red	1290 F.	Deep Orange	2000 F.
Dull Cherry	1480 F.	Middle Orange	2100 F.
Cherry Red	1650 F.	Clear Orange	2190 F.
Bright Cherry	1820 F.	Lemon Yellow	2380 F.
Rose	1900 F.	White	2600 F.

The temperatures of the retorts affect the carbonization of coal considerably, and invariably a greater volume of gas per unit of coal is made as the temperature becomes higher, whilst at the same time the quality of the gas will diminish. In experimental tests it has been found possible to completely carbonize coal at 750°F., but the results of the distillation principally takes a liquid form, and the percentage of permanent gases is comparatively small, and of high illuminating value. As the temperature increases the percentage of gas increases, whilst the liquid products decrease, and coincident with this, the quality of gas will decrease and the liquid products become more dense.

Under average conditions the yield of gas per ton of coal (2,000 pounds) at a distillation temperature of 1,400°F. will be about 8,900 cubic feet, with an illuminating power of 18.20 candles; whilst at a temperature of 1,800°F. the make per ton will be about 12,000 cubic feet with a candle power of 14.25.

CONDENSING AND PURIFYING PLANT: The crude gas as it leaves the retort consists chiefly of hydrocarbons of varying densities, a portion of which are permanent at atmospheric temperatures, and a portion of which must necessarily condense to a liquid or solid state as the temperature lowers. Briefly, the composition of the gas at this stage is in accordance with the following table:

TABLE 8.
DISTILLATES OF COAL.

Name of Gas	Formula	State at Ordinary Pressure and Temperature
Hydrogen	H_2	Gas
Methane	CH_4	Gas
Ethylene	C_2H_4	Gas
Carbon Monoxide	CO	Gas
Carbon Dioxide	CO_2	Gas
Hydrogen Sulphide	H_2S	Gas
Ammonia	NH_3	Gas
Water Vapor	H_2O	Liquid
Benzine	C_6H_6	Liquid
Carbon Bisulphide	CS_2	Liquid
Carbon	C	Solid
Napthalene	$C_{10}H_8$	Solid

When the gas enters the liquid in the hydraulic main its temperature is lowered to about 140°F, which results in the greater portion of condensable vapors being deposited therein as tar and ammonical compounds. As the gas leaves the main it still carries in suspension with it a certain proportion of liquid and solid matter, which condenses to light tar when the temperature is lowered to that of the atmosphere, and for the purpose of removing these tars the gas is drawn from the hydraulic main by an exhauster and passes through condensing apparatus. The exhauster is usually of the rotary type, and is driven by an engine or electric motor. The condenser may be arranged in various ways, but the principle is practically the same in each, and consists of a series of tubes through which the gas is passed so that it is subjected to the cooling action of the atmosphere. The pipes may be arranged in either a vertical or horizontal plane, and frequently their arrangement is such that they can be water-cooled during hot weather. In the vertical class the gas passes up one pipe and down the other, and the light tar which condenses passes down into a main where it is led to a tar well through a seal as shown in Fig. 15. The amount of condensing surface required per 1,000 cubic feet per day varies somewhat with different classes of coal, but may be from 6 to 10 superficial feet.

When the gases leaves the condenser they still contain certain impurities, which must be removed before the final product can be distributed for domestic or industrial use. These impurities consist chiefly of carbon dioxide CO_2, ammonia NH_3, carbon bisulphide CS_2, hydrogen sulphide H_2S, and traces of other organic compounds.

The first-named, carbon dioxide, is an odorless gas that will neither burn nor support combustion, and is injurious to respiration when inhaled by the human body. This gas has also a detrimental effect on the illuminating power of combustible gases, and in view of the fact that compounds of sulphur cannot be removed in its presence, it must necessarily be one of the first impurities to be removed. Under ordinary pressure and temperature the gas will dissolve in its own volume of water, forming carbonic acid, and its solubility may be increased under pressure.

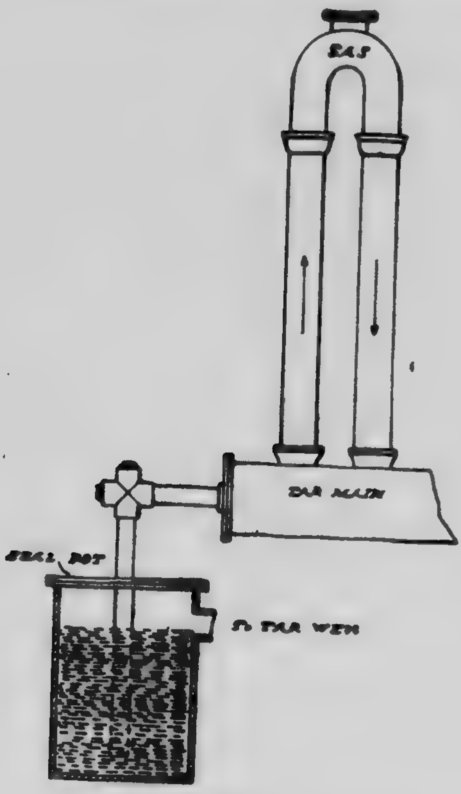

Figure 15

Ammonia is a compound of nitrogen and hydrogen, and is a colorless gas which possesses a very characteristic odor. It is extremely soluble in water and forms a solution which is poisonous and has a strong alkaline reaction.

It will be noted that the two gases referred to, CO_2 and NH_3, are soluble in water, and by bringing them into repeated contact with water they can be conveniently separated from the illuminating gases which it is desirous to retain.

The apparatus by which the ammonia and carbon dioxide is removed may consist of a washer and scrubber, or a combination of the two. The washer usually consists of a cast iron rectangular vessel, filled to a certain depth with water through which the gas is caused to pass in finely divided streams. This has the effect of removing a certain amount of ammonia and carbon dioxide and also brings down any tar which may have been carried with the gas through the condensers.

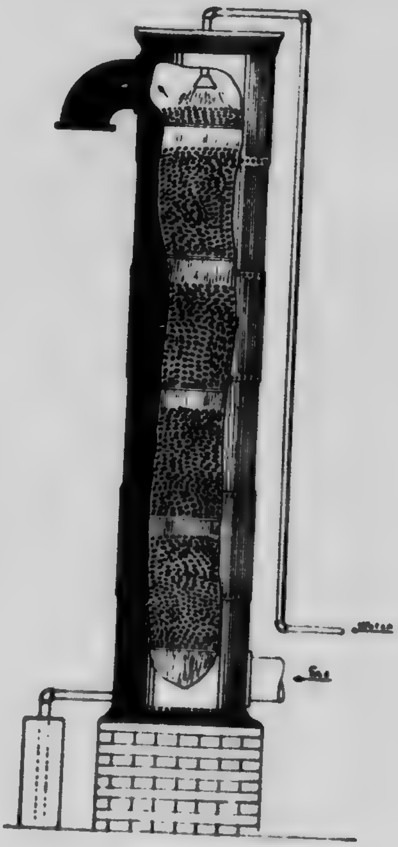

Figure 16

On leaving the washer the gas is passed up the scrubber, which is a cylindrical tower (Fig. 16) filled with hard coke, stones, or wooden trays, whilst water is sprayed in at the top and passes down over the material. By this means the gas is split into fine streams and brought repeatedly in contact with water, which serves to eliminate the remaining ammonia and carbon dioxide, which passes off at the bottom through a seal pot, whilst the gas passes off at the top for further treatment.

The compound carbon bisulphide (CS_2) is a heavy colorless liquid which boils at 117°F. In the retort this liquid volatilizes, and its vapors are carried with the gas until the temperature is lowered, when the impurity condenses to a liquid and is deposited in the gas mains where it flows to a drip pot.

The remaining impurity, hydrogen sulphide (H_2S) is a colorles-gas which is very poisonous and possesses a very offensive odor. It is produced by the free hydrogen in the retort combining with sulphur liberated from iron pyrites FeS, in the coal, and by bringing the gas in contact with an oxide of iron FeO at ordinary temperatures the hydrogen will take up the oxygen atom and liberate the sulphur, which re-combines with the iron and produces iron sulphide.

The coal gas may contain from 2 to 8 grains of hydrogen sulphide per cubic foot, and in order to remove this the gases are passed through a series of vessels known as *purifying boxes*, These vessels may be of various shapes, but are frequently rectangular, and are made of cast iron, with a movable cover of mild steel. They are fitted internally with angle irons which are adapted to support a series of wooden trays or grids upon which the purifying material is placed. The material employed may vary in different localities, but the one most commonly used is some form of ferric oxide. In many parts of the British Isles the material employed is obtained from the peat bogs of Ireland, and contains about 25 per cent. of Fe_2O_3, the remainder of which is peaty matter and moisture. This matter is commercially known as *Bog Ore*. In the U. S. A. and Canada, however, the material is generally a mixture of rusted iron borings and wood shavings or other spongy matter, the purpose of which is to render the material porous, so that the gas can be passed through it without causing an excessive back pressure The best percentage of borings to be used is a subject upon which gas engineers differ somewhat, but a good average may be taken as:

16 pounds of rusted iron borings.
1 bushel of wood shavings.
1 pound of lime.
1 pound of salt.

It may be stated that the small percentage of lime and salt are usually placed in the mixture to give it an alkaline reaction, and thereby neutralizes any carbon dioxide that has not been brought down in the scrubbers. This mixture is placed in the box on the supporting grids at a depth of about 6 or 8 feet so as to form a pair of compartments as shown in Fig. 17. The gases enter the box at *a* whence they pass through each layer of material, and again mix together before entering the next box or series of compartments.

The chemical principle involved in this purification is that the hydrogen of the hydrogen sulphide H_2S has greater affinity for the oxygen of the ferric oxide (Fe_2O_3) than its combining element Fe, which causes a reaction to take place as follows.

$$Fe_2O+3H_2S=Fe_2S_3+3H_2O.$$

This produces ferric sulphide and water, the latter of which is removed from the boxes by suitable drains. The sulphide, however, remains in the boxes for a certain length of time until the entire material has undergone reaction, when it is removed and the boxes re-charged with another supply of purifying material. When the ferric sulphide is exposed to the action of the atmosphere, the iron is oxidized by the oxygen of the air which liberates free sulphur as follows:

$$2\ Fe_2S_3+3\ O_2=2\ Fe_2O_3+S.$$

This reaction converts the ferric sulphide into oxide so that it can again be employed as a purifying agent. The reaction takes place three or four times, after which the material becomes loaded with free sulphur and has to be destroyed.

It may be stated that the purifying capacity of the boxes should be in accordance with the output of the gas in order to accomplish the work efficiently. In a medium-sized plant there is usually a battery of four boxes, one of which is kept in reserve, so that only three are in operation. Each of these are let down in order for removal of material about every fourth month, so that each individual box is let down once in 12 months. Assuming that one ton of new oxide will under average conditions purify the gas from 225 tons of coal; and that the daily output of the plant is 500,000 cubic feet at an average of 10,000 cubic feet per ton of coal, the amount of coal carbonized per day will be approximately 50 tons or 18,250 tons per year. If one ton of oxide will neutralize the hydrogen sulphide in 225 tons of coal, the amount of purifying material converted to sulphide per year will be $\frac{18,250}{225} = 81.11$ tons, and from this the necessary capacity of the purifying boxes can be computed.

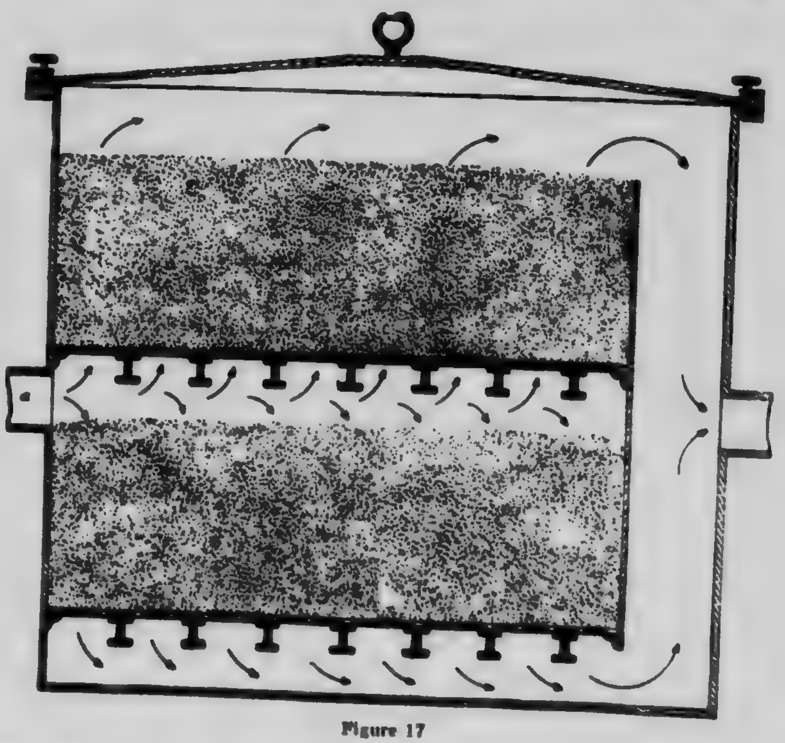

Figure 17

When the gas leaves the purifiers, it is ready for commercial distribution, and it is passed to a storage holder through a station meter by which the volume is measured. This meter may be of the wet type, the rotary, or the venturi;

but the one most commonly used is the first named. This class of meter (Fig. 18), is the simplest in construction and is believed to be the most accurate. The gas enters the meter at *a*, and passes into partition *b* that is just rising out of the water, which must be kept at a constant level by an overflow. This serves to revolve the cylinder and pass a definite volume into each partition before any is allowed to pass to the main outlet pipe. The inner ends of each partition are curved so that they dip under the water and prevent the gas from entering any other than the one rising out of the water. The outer end of partition *c* is still under water, and no gas can therefore pass from it until the cylinder revolves so that the edge is clear, whilst the inlet is closed by the inner end of partition *b*. By this means a definite volume of gas has to be placed in partition *c*, and as partition *b* fills up and revolves the cylinder, the outer rim of partition *c* is raised out of the water and the gas allowed to pass to the storage holder which supplies the street mains. The capacity of each partition depends upon the water level within the meter, which is indicated on the exterior by suitable gauges and must be kept at a constant level to insure an accurate measurement. The axis of the cylinder is connected through gearing to a suitable dial which records the amount of gas passed through.

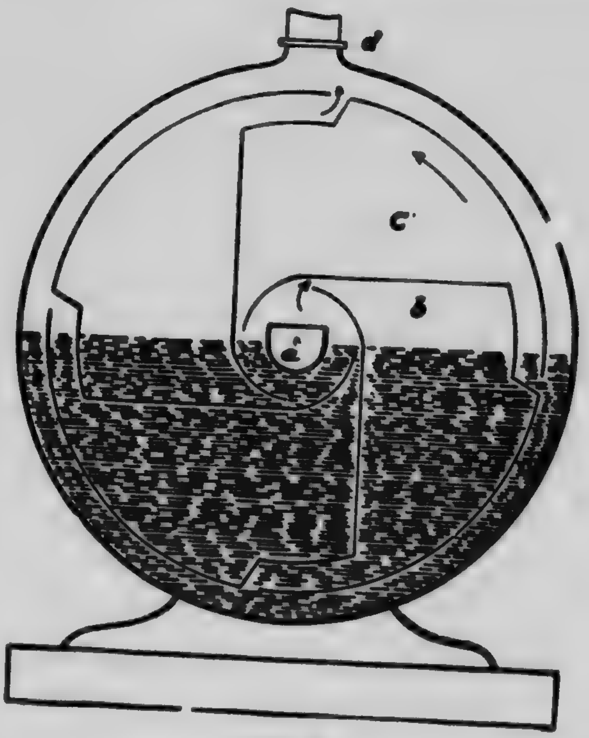

Figure 18

PLANT OPERATION AND REPAIR: When putting a coal plant in operation, the first important proceeding is that of heating up the new bench. In the first place the bench should have been allowed to stand for at least one month after its completion, during which time the dampers and air holes should have been left open to ensure a thorough drying out of the setting. When the fire is started in the producer, it should be built as low as possible and kept at this stage while ever moisture is seen to arise from the brickwork. This may take a week or more according to weather conditions, and a free circulation of air should be allowed to pass over the fire so that the setting will receive a good supply of hot, dry air. When the setting has been thoroughly dried out, and the bench is to be heated up, the secondary air ports are first closed, after which the fire in the producer isbuilt up and the supply of primary air regulated by dampers so that the fire will slowly build up and generate producer gas. When the interior of the retorts begin to show a uniform dull red color, the secondary air dampers are opened very slightly, and increased with caution until the retorts show a bright red color.

The retorts are now at working temperature, and the standpipes should be made firm in the sockets with lime, and a charge of coal about half the usual quantity placed in the retorts. It should be here noted that the dip pipes are sealed in the hydraulic main, after which the retort doors are securely fastened when the gas begins to distill off.

When the plant has been put in operation, the first important duty of the retort house foreman is that of keeping up a regularity of the drawing and charging periods, and he should be present at every such period and see that the stand-pipes are kept clear. It may here be pointed out that a portion of hydrocarbons condense to tar and lampblack when passing up the standpipes, which adheres to the pipe and tends to stop them up. For this reason the foreman in charge should see that they are opened at every charging period, by passing an iron bar which is twisted at one end so that it may be bored through the deposits. The tool used for this purpose is known as the *Auger*. It occasionally happens that the deposits are too hard to be broken by the auger, and when this occurs a charge must be missed, the connection between the retort and hydraulic main broken, and a small wood fire built in the retort mouthpiece. This will usually burn out the carbon or loosen it so that it may be removed by the auger, and if not, the standpipe must be taken down and placed in a hot retort until the carbon has been completely burned out. During the gasmaking period the foreman should give frequent attention to the condition of the producer fire, and also observe the distance at which the blue flame travels in the flues, and adjust the secondary air accordingly, and thereby prevent any combustible matter passing up the chimney.

In the distillation of coal, a portion of the hydrocarbons are brought in contact with the hot walls of the retort which decomposes them into their component parts. This liberates free hydrogen which passes off in the gas, while the carbon is deposited on the walls of the retort. These deposits increase daily and consequently reduce the efficiency and capacity of the retort, and in due course of time it must be removed.

The removal of these deposits, which is known as *scrufing*, is accomplished by letting the retorts off gasmaking for one or two charges, and then building up a flue along the bottom of the retort so that air is drawn along it and returns along the sides of the retort. The air so admitted supports the combustion of the carbon, the products of which pass up the standpipe which provides a draft for the incoming air. This has the effect of loosening the carbon, after which it may be removed by chisel bars.

After continued service the retorts frequently become cracked or broken in places by unusual heats, or damage from charging machines or shovels. When this is seen it is necessary to patch the retorts by blocks of firebrick and cement. The cement used is generally a composition of ground firebrick and fireclay, in which it is advisable to add about one handful of borax to every bucker. The mixture is kneeded up until it is stiff, and when applied to the hot wall of the retort, the flux begins to act immediately, and the cement soon hardens.

If a bench has been carefully handled it will generally give good service for two years or more, but after this it is usually more economical to replace with new material than attempt to continually repair the old. Invariably the setting wears out before the furnace, and if it is desirous to allow the latter to remain, the front wall, retorts, and supporting walls only are pulled down and rebuilt.

When such renewals are to be made, it is necessary to let down the bench, and this should proceed by first charging the retorts with fresh coal, then closing all the air dampers, and nearly closing the stack damper. By this means the new charge will absorb the heat from the setting, and when the charges have been well carbonized, the connections between the bench and hydraulic main are broken and plugged off, so as to prevent the liability of gas returning into the retorts. Under these conditions the bench will slowly cool down without any unequal contraction,and after standing a few days the retorts can be opened and the charges with-drawn, when the re-construction may commence.

EXHAUSTING: When the gas leaves the retorts the pressure forces it through the liquid seal in the hydraulic main, from which it is drawn by means of an exhauster. This may be of various design, but in the writer's opinion, the simplest and most efficient is the rotary type driven by a steam engine or electric motor. The employment of the exhauster originated with the introduction of fireclay retorts, owing the their porosity and comparatively high temperatures at which they could be operated. The primary objects of the exhauster was to effect the withdrawal of gas as quickly as it was distilled, and to overcome the resistance offered to its passage through the scrubbing and purifying plant.

The exhauster room is provided with three gauges, one of which is in communication with the hydraulic main; a second on the inlet main of the exhauster; and a third on the outlet main. These gauges constitute columns of water graduated to inches, and the first gauge shows the pressure of the retorts after the dip pipe seal allowance is made; the second shows the suction in the gas mains from the retort house to the exhauster; and the third shows the back pressure exerted upon the exhauster by the scrubbing and purifying plant. With this guidance and the knowledge of vacuum and pressure at different parts of the plant, the exhauster room attendant has control of the works so far as the maintenance of uniform pressures and vacuum is concerned, and by keeping a constant vacuum on the hydraulic main the operation of the retorts is greatly improved. Briefly, the advantages obtained by the use of the exhauster may be stated as follows:

(1) It improves the quality of the gas by enabling greater uniformity in its distillation.

(2) It reduces the percentage of carbon deposits and thereby increases the capacity and efficiency of the retorts.

(3) It lengthens the life of the retorts by the avoidance of excessive pressures.

(4) It reduces the percentage of fuel used in the producer by minimizing the loss of heat through excessive carbon deposits.

(5) It provides a constant pressure on the scrubbing and purifying plant, and minimizes the risk of explosion by immediately indicating abnormal back pressures.

COMPOSITION OF CRUDE OIL: The composition of crude oil is that of a variety of hydrocarbons, which may occur in a gaseous, liquid or solid state according to the following table:

TABLE 9.

CRUDE OIL (Paraffin Series)

Formula	Name of Compound	Percentage of Carbon	Percentage of Hydrogen	Boiling Point Degs. F.
	GASES			
CH_4	Methane	75.00	25.00	253
C_2H_6	Ethane	80.00	20.00	135
C_3H_8	Propane	81.81	18.19	49
C_4H_{10}	Butane	82.80	17.20	34
	LIQUIDS			
C_5H_{12}	Pentane	83.33	16.67	86
C_6H_{14}	Hexane	83.72	16.28	156
C_7H_{16}	Heptane	84.00	16.00	208
C_8H_{18}	Octane	84.21	16.79	257
C_9H_{20}	Nomane	84.38	15.62	277
$C_{10}H_{22}$	Decane	84.51	15.49	316
$C_{11}H_{24}$	Endecane	84.61	15.39	360
$C_{12}H_{26}$	Dodecane	84.70	15.30	386
$C_{13}H_{28}$	Tridecane	84.78	15.22	420
$C_{14}H_{30}$	Tetradecane	84.85	15.15	462
$C_{15}H_{32}$	Pentadecane	84.90	15.10	497
$C_{16}H_{34}$	Hexadecane	84.94	15.06	536
$C_{18}H_{38}$	Octadecane	85.04	14.96	536
$C_{20}H_{42}$	Octadecane	85.11	14.89	536
$C_{22}H_{46}$	Octadecane	85.18	14.82	536
$C_{25}H_{52}$	Octadecane	85.23	14.77	536
	SOLIDS			
$C_{27}H_{56}$	Myrical	85.26	14.74	536
$C_{30}H_{62}$	Ceryl	85.31	14.69	699

This series of hydrocarbons are known as the *paraffin* or methane series, as each individual hydrocarbon bears a relation to the first of the series, which is methane CH_4. By referring to the formulas of each compound, it is seen that the number of hydrogen atoms is twice the number of carbon atoms plus two, from which arises the general formula CnH_2n+2, by which the paraffin series is frequently symbolized. The gas CH_4 is the simplest of the series, and from it about 35 different compounds are built up; ranging from the gaseous to the solid state.

In the previous table, which constitutes the most important, the first four are gases at ordinary temperature, and the first of the liquids—pentane C_5H_{12}, volatilizes at 86°F. From this the boiling points of the various compounds gradually rise to the solid state, when it is necessary to employ high temperatures to affect distillation.

Whilst the paraffin series are the most common, there are a number of other series of varied importance. The first of these is the olefines, of which *ethylene* C_2H_4 is the simplest. This series is referred to by the general formula $Cn\,H_{2n}$, from which it is seen that the olefines contain two hydrogen atoms less than the paraffins, or that the hydrogen atoms are just double the carbon atoms.

A series of compounds which closely resemble the paraffins in their properties are those known as the *napthenes*. They are, however, more condensed than the paraffin series, and have the same formula as the olefines but different properties. This series which have a similar composition to another series, but different properties, are known as the *isomers* of the series of which they have the same composition; hence the *napthenes* are isomers of the *olefines*.

The next series is the *acetylene*, which is designated by the formula $C_nH_{2n}-2$, and contains two hydrogen atoms less than the olefines. The first gas of this series is acetylene C_2H_2.

The *benzine* series is the next most important, and has the general formula $C_nH_{2n}-6$. The first of these is benzine C_6H_6, and they are sometimes referred to as the *aromatic* series, owing to the aromatic odors which most of them possess.

The composition of petroleum varies in different localities, and the American oils consist chieffy of hydrocarbons of the paraffin series, with a small percentage of benzines, and a trace of napthenes. They also invariably contain a small percentage of oxygen and sulphur compounds. The Eastern and Western fields are slightly different in that the solid residue or base in the eastern fields is generally paraffin, whilst the base in the western fields is asphalt.

In the Russian oil fields the crude oil consists chiefly of napthenes, and slight traces of other hydrocarbons, oxygen and sulphur compounds; whilst in Roumania and East Indies the oils are a mixture of paraffins, napthenes and benzines of varied proportions.

PURCHASING: The value of fuel oil is largely in relation with the specific gravity, owing to the fact that its volatility is inversely proportional to it. Oil which has a low specific gravity produces a greater percentage of lighter hydrocarbons, and invariably contains some natural gas in solution; whilst heavy oils contain higher percentages of sulphur, asphalt, or paraffin, and deposit more solid matter.

The specific gravity is determined by the Baume hydrometer, which is for liquids lighter than water, and is frequently combined with a temperature thermometer. The graduations on the hydrometer commence at 10°, which is equal to water at 60°F., and the scale rises as the specific gravity lowers according to the following table:

TABLE 10.

SPECIFIC GRAVITIES CORRESPONDING TO BEAUME HYDROMETER

Degrees Beaume	Spec. Grav.	Degrees Beaume	Spec. Grav.
10	1.0000	31	.8695
11	.9929	32	.8642
12	.9859	33	.8589
13	.9790	34	.8536
14	.9722	35	.8484
15	.9655	36	.8434
16	.9589	37	.8383
17	.9524	38	.8333
18	.9459	39	.8284
19	.9396	40	.8235
20	.9333	41	.8187
21	.9271	42	.8139
22	.9210	43	.8092
23	.9150	44	.8046
24	.9091	45	.8000
25	.9032	46	.7958
25	.8974	47	.7909
27	.8919	48	.7860
28	.8861	49	.7821
29	.8805	50	.7778
30	.8750	51	.7735

It is important that the temperature is also noted and corrected to 60°F. by means of a coefficient which may vary .00033 for very heavy oils to .00068 for the lightest oil—pentane. The range between these coefficients is only used for very accurate work, such as experimental, and the coefficient .0004 is adopted for general use by several public commissions, and should be sufficiently accurate in determining the value of an oil to be used as fuel.

The specific gravity, as indicated by the Baume hydrometer, is shown in Table 10 up to 51°, and can be computed for a higher degree by the formula:

$$\text{Spec. Gravity} = \frac{140}{130+B^\circ},$$

for instance, if the reading is 60°B., the specific gravity is:

$$\frac{140}{130+60} = .7368.$$

The gravity at a temperature other than 60°F., is elevated or depressed when the temperature is below or above the standard. and can be corrected by multiplying every 1°F. by .0004, and substracting or adding accordingly; hence an oil with a specific gravity of .7368 at 75°F. would be corrected to $.7368+(15\times.004)=.7428$.

The most important factors, however, in setting the price of fuel oil is its chemical composition and freedom from suspended matter; and its adaptability to produce the greatest proportion of heat-giving gases. This can be determined only by analysis.

STORAGE: One of the most important considerations in the use of fuel oil is the location of storage tanks so that they comply with the state rules and regulations regarding the prevention of fire. These rules vary somewhat in different states and provinces, but, in general, they call for a steel constructed tank with plates of definite sizes according to the capacity of the tank. A 5000-gallon tank would invariably require a 3/16 inch steel plate with a 1/4 inch head; whilst up to 10,000 they would require a 1/4 shell with 5/16 inch heads

The location of oil tanks vary with the size and purpose, and small tanks are frequently located in the sidewalk adjoining the furnace room in which the oil is used, whilst tanks used in connection with steam boilers or other industrial processes in which the oil is needed in large quantities, are generally located above the ground in concrete basins, and are adapted to feed the oil burners or sprays by gravity.

A small tank illustration in connection with a bakery is illustrated in Fig. 19, and is suitable for other businesses of a similar nature in which solid fuel is undesirable.

The location of tanks influences the system of unloading oil cars, and in underground installations as illustrated above, the oil is invariably discharged to the storage tank by gravity. When the storage is some distance from the burners it is more satisfactory to locate the tanks so that they feed the burners by gravity, as this insures a constant supply at all times, which enables the burners to be adjusted better for complete gasification. This arrangement makes it necessary to unload the car by pumping or compressed air. The latter system consists essentially of an oil discharge leading to the bottom of the oil car, and

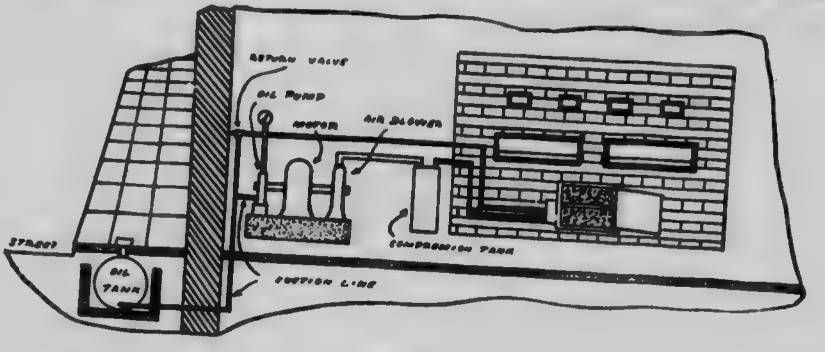

Figure 19

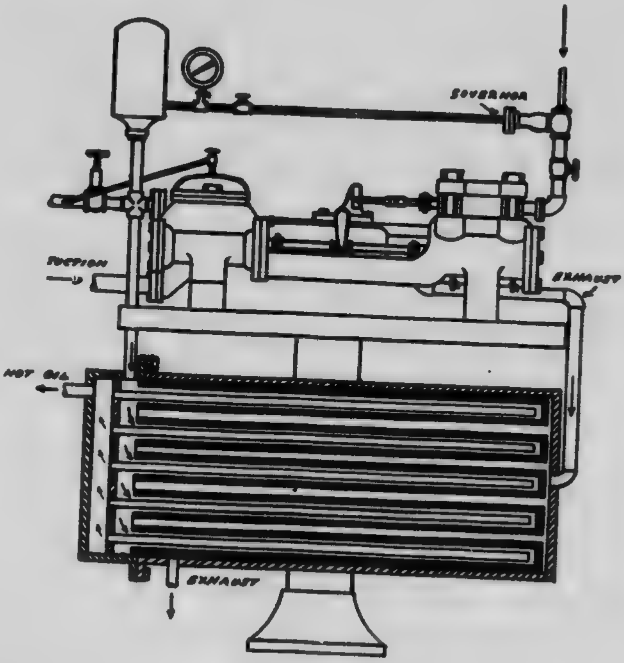

Figure 20

an air line above the surface of the oil which creates a downward pressure and causes the oil to pass off through the discharge. This system is very satisfactory where compressed air can be conveniently had, or when the oil car is some distance from the pumping outfit.

COMBUSTION: Before the oil enters the burners or sprays it is advisable to raise the temperature so as to lower the density and enable it to be more easily atomized. The system of heating varies somewhat with the size and purpose of the plant, and there are many designs of heating and pumping systems combined. In large installations, such as used for steam boilers, the oil may be heated by live steam, whilst in small units, as in the bakery illustration or other dry heat process, the exhaust steam from the pump is utilized. A design of this class is shown in Fig. 20 in which the discharge pressure of the pump is kept practically constant by means of a governor actuated from the oil line.

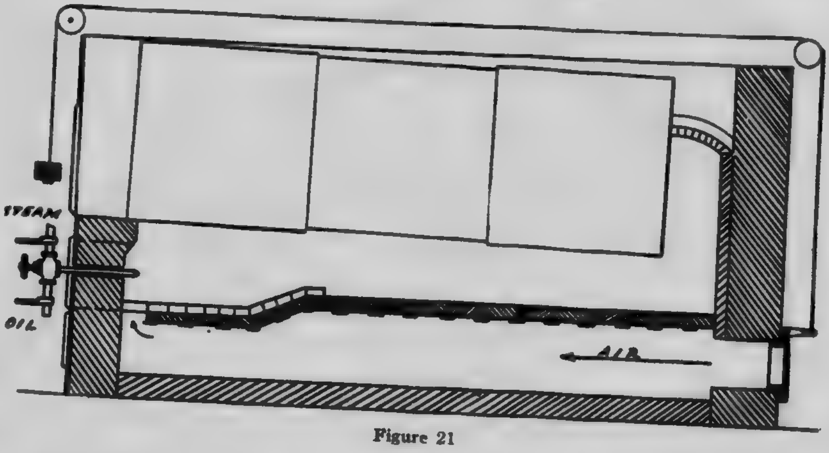

Figure 21

In order to get good results from the combustion of oil, it is very important that the furnace is carefully designed for the purpose. The arrangement of the setting differs with the different apparatus, but an important consideration in their design is to raise the temperature of the air for combustion previous to mixing with the oil vapors in the combustion chamber. This is illustrated in connection with a tubular steam boiler in Fig. 21, in which it is seen that the air supply is from the rear of the boiler and has to travel the length of the setting before entering the combustion chamber.

The efficiency of oil burning equipment is largely influenced by the air supply. The indication of complete combustion is the production of a clear flame without smoke, but this does not prove whether the air supply is in excess or not. The results of the combustion of carbon is CO_2, and if a fuel consisting of 100 per cent. carbon was burned in adequate supply of air, the percentage of CO_2 present in the flue gases would be 20.7 by volume. The composition of fuel oil is a variety of hydrocarbons of varying densities, and the percentage of carbon decreases and the hydrogen increases as seen from Table 9, with the result that this percentage of carbon dioxide is never reached. The maximum theoretical CO_2 obtained by complete combustion depends on the percentage of carbon in the oil, and under the best conditions of furnace setting and air supply, the CO_2 is usually about 13 or 14 per cent. When the air supply is in excess to that required for combustion, the percentage of CO_2 in the flue gases is lowered in relation to it, and a large amount of heat is lost. The maintenance of the correct volume of air is therefore an important factor, and a CO_2 recording instrument is a desirable addition to the oil burning equipment. This should also be occasionally checked by a portable analyzing apparatus for determining the carbon monoxide CO, carbon dioxide CO_2, and oxygen O_2. The following table shows the relation between CO_2, excess air, and loss of fuel.

TABLE 11 (DUNN).

FLUE GASES (CO_2).

CO_2 per cent.	Excess Air per cent	Bt. Th. U. losses	Fuel Losses per cent.
15.6	0	0	.0
15.0	5	75	.4
14.0	10	[illegible]	1.0
13.0	[illegible]	[illegible]	1.7
12.0	28	[illegible]	2.4
11.0	40	[illegible]	3.4
10.0	51	[illegible]	4.6
9.0	70	[illegible]	6.0
8.0	[illegible]	[illegible]	7.8
7.0	[illegible]	1435	10.2
6.0	[illegible]	1900	12.3
5.0	198	2460	17.2
4.0	[illegible]	3205	23.5
3.0	306	4380	34.0
2.0	635	6340	54.5
		10150	

The CO_2 recording instrument should be located at a convenient position where it can be easily read, and the sampling tube connected with it should be inserted at the base of the chimney, or as near as possible to the point where the gases leave the heating surfaces. These instruments can also be used to determine air leakage by removing the sampling tube to different parts of the setting and comparing the readings. The furnace reading should have a slightly higher percentage of CO_2 than the base of the chimney, and when the difference between these two points is comparatively large under similar conditions, an air leakage between the two points is indicated. A draft gauge should be used in conjunction with the recorder and the draft reduced when the percentage of CO_2 is below the normal. The portable apparatus for complete analyses of the flue gases is illustrated in Fig. 104, Chapter 9.

BURNERS: The use of oil burners dates back 100 years or more, during which time they have been modified and improved in various ways. At the present time they are many different designs on the market, each of which claim to have some minor advantage. The general principle, however, is illustrated in Fig. 22. This burner which is known as the S. & P., has been widely used for steam generation in oil burning districts where the fuel is comparatively cheap, and for maritime purposes. Referring to the illustration, the oil is fed to the burner at *O*, and steam or air at *S*. The oil passes through the inner tube *t*, through which the flow is regulated by rod *r* which has a pointed end fitting the conical end of the atomizer *A*. The oil passes through the atomizer through radial perforations into the mixing chamber where it is met by steam or air under pressure, and broken up into a fine spray. The channels through which the mixture passes to the burner head is formed as slots at the end of the oil tube.

The temperature of the oil at the burner has considerable influence in obtaining proper atomization, and good burners are designed to raise the temperature by radiation from the steam before bringing the oil and steam into contact. In the previous illustration it is seen that the oil and steam pass to the atomizer in parallel for this purpose. It is important, however, to keep the temperature of the oil below the flash point, as premature volatilization is liable to precipitate carbon in the burner tip and lower the efficiency of the burner considerably. If the temperature is raised as high as possible, and still kept slightly below the flash point, it requires less steam or air to break up the oil, and atomization is more complete.

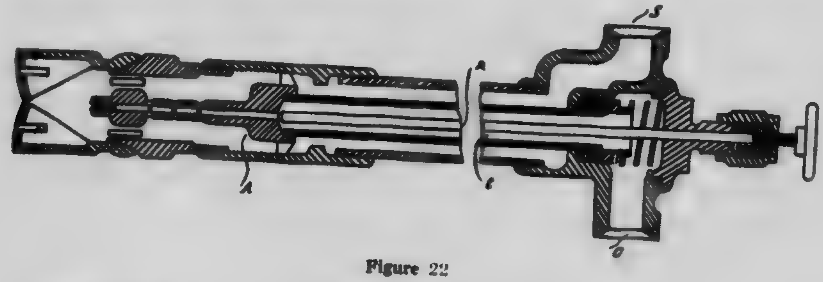

Figure 22

CHEMISTRY OF OIL GAS: The chemical principles involved in the destructive distillation of oil for gas production is much the same as in the destructive distillation of coal. The decomposition, of course, varies slightly with different grades of oil, but in general, it may be said that the application of intense heat causes the hydrocarbons of the paraffin series C_nH_{2n+2} to distill into those of the olefines C_nH_{2n}, which, in turn go over on continued exposure to high temperatures into benzines C_nH_{2n-6}, and finally form compounds of the napthalene C_nH_{2n-12} and anthracene C_nH_{2n-18} series.

From the foregoing it is obvious that the prolonged exposure of oil to high tempera'ures has the effect of robbing the hydrocarbons of their hydrogens atoms, and producing compound which contain large percentages of carbon; and if the decomposition is carried too far, the compounds high in carbon will be deposited within the distillation chamber in a solid state. In modern practice of oil gas manufacture, the liquid hydrocarbons are brought into contact with heated surfaces under suitable temperatures which has the effect of breaking up complexed hydrocarbons into those of a simpler composition. It is found, however, that this decomposition is invariably associated by a depositing of compounds high in carbons, and one of the most important items to be considered in the design of oil gas apparatus is the minimizing of these deposits consistent with the efficient operation of the plant.

OIL GAS APPARATUS: The manufacture of gases from crude oil has been tried in various ways, and a process was known as early as 1815, when *Gorden* took out a patent in England for a method of compressing the gas into tanks for transportation. The first plant, however, of any importance was patented by *Julius Pintsch* in 1873, which consisted of an upper retort into which the oil was conveyed and delivered into a pan heated to cherry red. This served to evaporate the oil, and the vapors were passed through a lower retort filled with brick heated to redness, by which the oil vapors were fixed into permanent gases. The gases were then passed through a washer and condenser for purification and compressed into tanks for transportation. Until recent years these plants were widely used for the manufacture of transportable gases, particularly for lighting on the passenger railroad service. The illuminating power of gases made under these conditions is very high, and it is never distributed for commercial purposes without being diluted with gases of lower value. In modern methods of manufacture the process may be either continuous or intermittent, according to the quality of gas desired.

In the continuous process, which is used for the manufacture of gases for industrial purposes, the principle involved is that of producing interaction between an hydrocarbon and air to affect partial combustion to keep up the temperature of the generating apparatus.

In the intermittent system the gas apparatus is heated during one period, and oil gases generated during another period. This takes place alternately, and each period is of a few minutes' duration. This system is employed for the manufacture of gases for commercial distribution. Under these conditions the gases produced are entirely the products from oil, which has a very high illuminating and calorific value, and is too rich to be economically distributed. It is, therefore, diluted with water gas (H_2+CO) to a definite degree, so that the final mixture is in the region of 600 B.Th.U. per cubic foot. The intermittent process is a development of the original water gas process, which is described fully in a work by the same author "Elements of Water Gas." The water gas apparatus consists, briefly, of a generator, carburetter and superheater. The generator is a chamber provided with grate bars on which is kept a bed of carbon containing fuel of varied description. The carburetter and superheater are filled with checker brickwork for the absorption and evolution of heat at different stages of the process. In the heating period a blast of air is passed through the fire in the generator, which raises it to incandescence and generates CO_2 in the lower part of the bed, which is reduced to CO on passing up the fuel. The CO is passed to the carburetter and superheater to be met by secondary air and re-burned as CO_2. This imparts heat to the checkerwork and raises the temperature to that required. This period continues for three or four minutes during which time the blast gases are passed to the atmosphere. When the gasmaking period commences, the apparatus is closed in line with a gas holder, and steam passed through the fuel in the generator, whilst oil is passed into the carburetter. The steam H_2O is broken up by the intense heat, and the oxygen is taken up by the carbon to produce carbon monoxide, and free hydrogen is liberated. The oil vapors produced in the carburetter are mixed with the water gas for enrichment, and the mixture of gases permanently fixed on passing through the superheater. The gasmaking period continues for about five minutes, after which the fire has to be revived by air, and the blasting period is recommenced. The fuel consumed per 1,000 cubic feet in this process is approximately 35 pounds of coal and 3 gallons (imperial) of oil. These figures vary somewhat with operating conditions and classes of fuel.

The intermittent process of oil gas manufacture is very similar to the water gas process, and differs chiefly in that oil is used for heating instead of solid fuel.

The oil gas can be made in the water gas apparatus by filling the generator with checkerbricks the same as the carburetter and superheater, and employing oil burners for combustion during the heating period. The manufacture of gas according to this system does not require any special grade of oil, and the crude product direct from the wells or residues from the refineries may be used.

The use of crude oil causes a deposit of carbon on the checkerbrick by the breaking up of the heavy and complexed hydrocarbons, and liberation of free carbon and hydrogen. The relative proportion of these deposits is influenced by the temperature of the checkerbrick, and higher heats will invarably deposit a greater proportion of carbon. It is necessary however, to keep the heats as high as possible in order to obtain the maximum amount of gas per gallon of oil. The temperature of the apparatus falls rapidly when the run of gas commences, and may be 200° or 500° F. less at the end of the run that at the beginning. It is evident, then, that the correct theoretical temperature for economical gasmaking is between the two points, and under these conditions the greatest proportion of carbon is deposited at the beginning of the run when the heat is above the correct temperature.

In the early days of oil gas manufacture, the carbon deposits caused a considerable lowering of the efficiency of the apparatus, but in recent years the system has been improved by adding steam to react with the carbon and generate water gas, and also using water gas generated in a separate apparatus to produce a suitable atmosphere and act as a catalyzing agent in the destructive distillation of oil.

JONES PRODUCER: The Jones Improved Producer is one of the best designs of apparatus for making "crude oil water gas," and has been widely employed in the Western States of America. This is illustrated in Fig. 23.

The apparatus consists of two generators *G'* and *G''*, cylindrically in shape; the latter of which is longer than the former, and is connected therewith by a rectangular throat piece *t*. The generators are lined with firebrick or other refractory material, and are divided by arches *A'* and *A''* to form chambers C, C', C'', C_3. The space between the chambers is filled with a checkerwork of firebrick, the purpose of which is to store up as much heat as possible for the destructive distillation of oil during the gasmaking period.

At the top of generator *G'* there is provided a valve *V* for the admission of air under pressure to support combustion of oil for heating the apparatus, and at or near the middle of the longer generator *G''*, there is located a common outlet *O* for both generators. At the bottom of generator *G''* there is located an inlet *i* for the admission of secondary air, and at the top of generator, a stack valve *S* is provided to conduct the products of combustion to the atmosphere.

In the operation of this apparatus, the checkerwork in the chambers is first heated to the desired temperature for gasmaking by the combustion of oil admitted through pipes *p* to the top of generator *G'*. The air for combustion is admitted at valve *V* with optional secondary air at *i*, and the burning gases pass through the chambers in a wave-like motion, and impart heat to the checkerwork, and finally discharge through the stack valve *S* to the atmosphere. When the temperature of the brickwork has been heated to the desired point, which

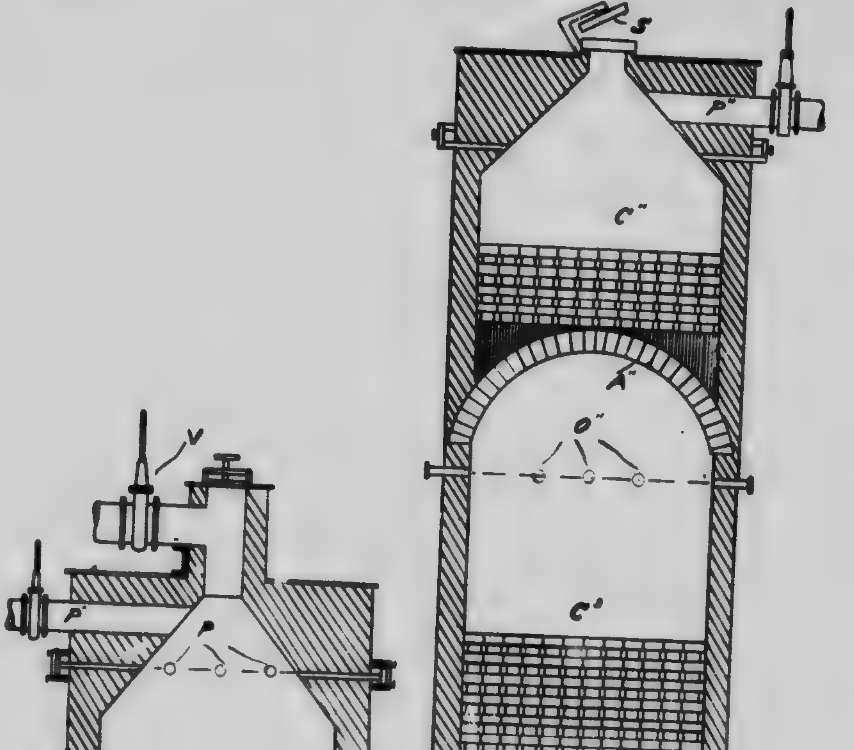

Figure 23.

may be from 1,600°F. to 2,400°F., according to the nature of the oil, the heating period is brought to a close by cutting off the oil and air at *p* and *V*, respectively, and then closing stack valve *S*. During the said heating period the oil is wholly or partially consumed in chamber *C*, and carbon and lampblack is invariably deposited on the checkerwork of the chamber.

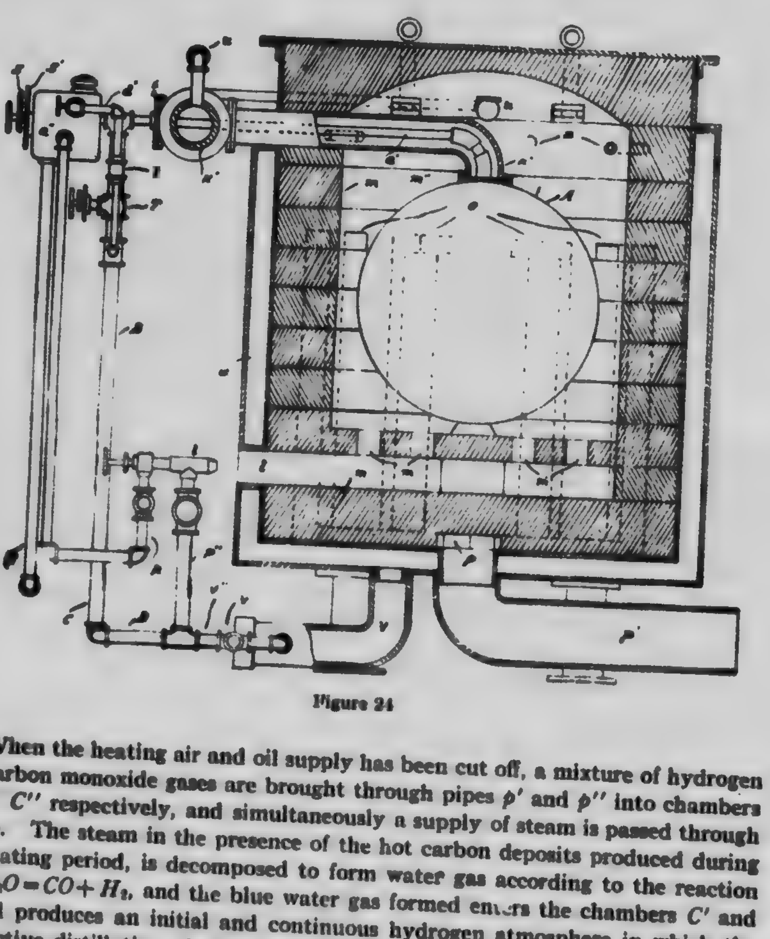

Figure 24

When the heating air and oil supply has been cut off, a mixture of hydrogen and carbon monoxide gases are brought through pipes *p'* and *p''* into chambers *C* and *C''* respectively, and simultaneously a supply of steam is passed through pipe *p*. The steam in the presence of the hot carbon deposits produced during the heating period, is decomposed to form water gas according to the reaction $C + H_2O = CO + H_2$, and the blue water gas formed enters the chambers *C'* and C^3 and produces an initial and continuous hydrogen atmosphere in which the destructive distillation of oil takes place. A supply of hot oil is then injected through pipes *O'* and *O''* in a fine atomized state, and the oil breaking up in the presence of the hydrogen, carbon monoxide, and superheated steam, passes to and through the chambers *C'* and C^3, respectively to the gas outlet *O*, which is provided with an hydraulic seal to prevent the return of gases during the heating period when the stack valve is open. After the gas making period proceeds for a given length of time, the checkerwork cools off, and the gasmaking steam and oil are cut off for the re-commencement of a heating period as previously described.

CONTINUOUS PROCESS: The continuous system is particularly suitable for industrial purposes, and the principle involved is that of admitting a relative proportion of air to affect partial combustion to keep up the temperature of the generating apparatus.

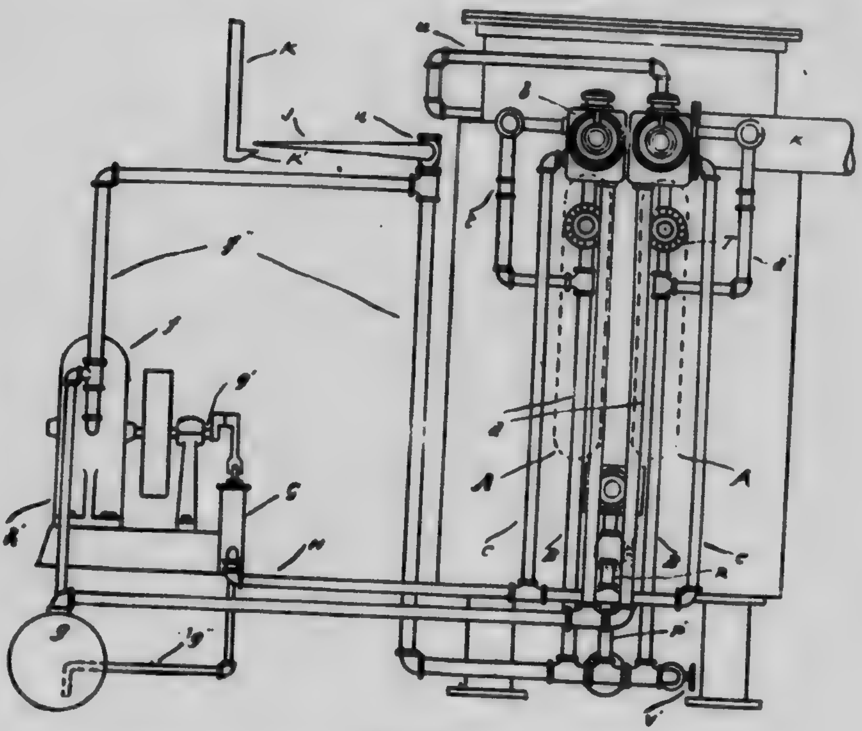

Figure 25

A design of apparatus of this class is illustrated in Figs. 24 to 26, in which *A* is a retort into which a mixture of crude oil and air is passed through the conduit *a'* and injector *a''*. The injector *a''* is shown more fully in Fig. 26, and constitutes an important unit in the efficient operation of the apparatus, and serves to control the mixture of air and oil. The air enters by way of pipe *B*, and the oil by means of tube *b'*, which dips into reservoir *b''*. The oil is led to the injector through pipe *C*, Fig. 24, and opens into reservoir *C'*, Fig. 25. The supply is kept slightly above the normal requirement, so that a constant level is kept at all times; an overflow being provided at *d* to take off the excess. A pipe *d'*, Fig. 24, maintains a constant air pressure, and opens into the space above the oil *d''*, Fig. 26. The oil supply to the retort *A* is controlled by the adjustment of a needle valve *e*, and passes through tube *f* into conduit *a'*. The air supply is maintained by a compressor *f'*, Fig. 25, and delivers the air through a tube *f''* which feeds into pipe *B*, and the oil is introduced at all times at a pressure bearing such a relation to the pressure of air that the ratio between them is maintained substantially constant for different air pressures.

The oil is forced to the injector by means of a pump G, which is connected to shafting g', and operated from a small motor which also operates the air compressor. The oil is drawn from a storage tank g through piping g'' and delivered through pipe H, which communicates with pipe C leading to the injector. A branch pipe h' leads from the air main f'' to the oil tank g and introduces an air pressure on the surface of the oil equal to the pressure of the oil in the reservoir of injector a''. A pipe b'' leads to a valve i provided with a lever arm j which is adapted to engage with a rod K through finger K'. The rod K is connected to a gas reservoir, which when filled to a predetermined height is adapted to engage the finger g' with lever j, which opens the valve i and releases the air pressures from pipe f''. By the reduction of pressure in the air main, the pressure of air and oil are simultaneously reduced, and the rate of gas making is reduced accordingly.

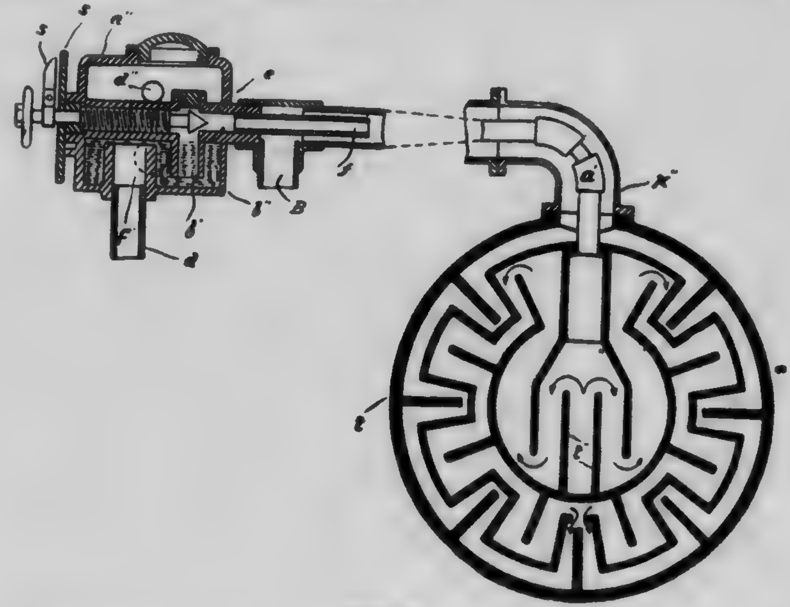

Figure 20

When the air and oil have passed through the injector they pass into retort A. Fig. 24, and flow too and fro along the baffled interior in the direction of the arrow, and finally discharge through the conduit K'' to the consuming appliances through the medium of a small gas reservoir.

On putting the retorts into operation, a mixture of air and oil is blown by means of a torch L into passage L', and passes through the main flue M around the retort. The burning gases then pass along the flues M' and are introduced into chamber M'' in which a vigorous combustion takes place. The products of combustion then pass through flues O into base flue p, and through pipe p' to the stack. The torch L is supplied with air by means of a branch pipe p'' from the air pipe B, and with oil by branch pipe R from the oil line C.

The needle valve *e* carries a pointer *S* which moves over a fixed graduated dial *S'* and shows the exact position of the valve. When the retort setting is first heated, the valve E is closed and also the valve *T* in the air line *B* until the temperature of the retort is raised to about 1,400°F. The air is then put at a desired value, and the oil reservoir *b* filled to the desired level, after which the valve *V* is opened, which introduces air into conduit *a'*. The needle valve *E* is then opened gradually to steadily increase the oil supply, and the mixture of oil and air enters the heated retort. The check valve *t'* prevents any back flow of air or oil from the feed device. On entering the hot retort the oil is volatilized and the vapor transverses along the baffles *t''* which has the effect of producing chemical reaction, accompanied by partial combustion and the production of a fixed combustible gas. The needle valve *E* is adjusted until a gas is produced which possesses the desired calorific value and composition, after which the production continues without further attention. The fixed gases discharge from the retort through the conduit *K''* which surrounds the pipe *a'*, and is adapted to heat the said pipe, so that the oil is partially vaporized previous to entering the retort.

When it is desired to make a gas of low calorific value, the percentage of air can be increased, and the temperature of the retort can be maintained by partial combustion without external heating. In most cases, however, the retorts require a little external heating, and this is effected by leading a portion of the gas from main *K''* to chamber *m'* by way of pipe *u*. The temperature of the retort is usually from 1,400° to 1,600°F., according to the quality of gas desired. The air for combustion of the gas is admitted through the conduit *v* by way of valve *v'* and branch pipe v'', and thence into the casing *w* to the retort heating chamber *m'* through holes *x*.

The retort temperatures are obtained by pyrometers of the thermoelectric type, and they remain substantially constant with varying air-feed pressures, and consequently varying ratios of gas production, while ever the ratio of oil and air is constant. If, however, the ratio is disturbed, the temperature of the retort will fluctuate and the gas will vary in its composition; for instance, if the quantity of oil is decreased the gas will contain less combustible matter, and the temperature of the retort will rise owing to the greater percentage of partial combustion taking place, resulting in the formation of more hydrogen and carbon monoxide and less hydrocarbon gases.

It is obvious from the above description that the quality of gas can be varied to suit different conditions, and a typical analysis of gas made with a retort temperature of 1,475°F. from an oil of .833 specific gravity, is as follows:

Name of Gas	Percentage by Volume.
Nitrogen	
Hydrocarbon	54.5
Hydrogen	25.6
Carbon Monoxide	7.2
Carbon Dioxide	7.0
Oxygen	5.4
	0.3

The heating value of gases having this composition is approximately 500 B. Th. U. per cubic foot.

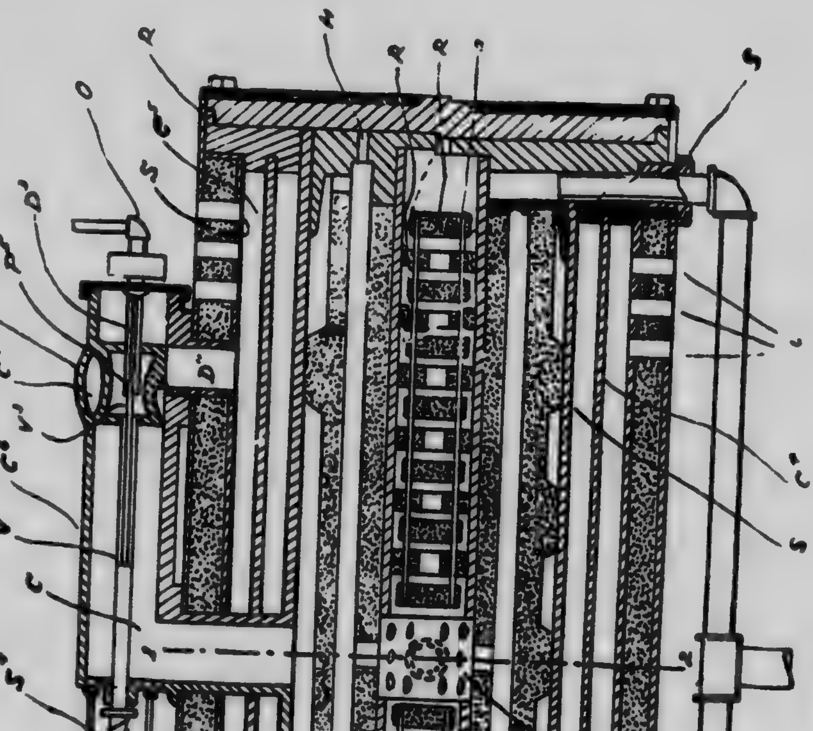

Figure 27

OIL GAS PRODUCER FOR INTERNAL COMBUSTION ENGINES: The use of crude oil for generating a gas as a fuel for internal combustion engines has been employed in various designs of carburetters particularly adapted for small units where it is impractical to employ a gas producer. In large engine units, however, it is more economical to employ a separate gas producer to generate the power gases from a liquid or solid fuel as desired. The solid fuel class is the most widely used, but in oil bearing regions the former class is generally the most economical.

A recent development in this class of producer is a form of apparatus which proposes to automatically regulate the temperature of the gas producing chamber or converter and prevent such from rising too high, and thereby avoiding excessive decomposition of the oil.

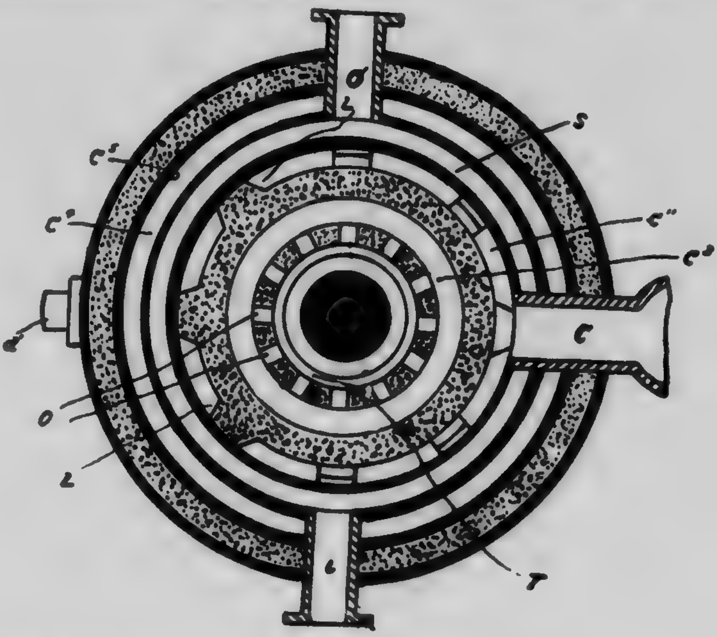

Figure 28

In Fig. 27 the converter is shown in longitudinal section, and Fig. 28 is a traverse section through lines 1—2 of the latter figure. The cylindrical casing, which constitutes the main shell of the converter, is shown at *C*, and is provided with an inlet connection C' for the admission of a mixture of oil and air which is to be converted to gas. A cylinder C'' of porous refractory material is located within the cylinder *C*, and spaced away from the walls thereof by means of lugs *L* formed at intervals on the surface of the cylinder C''. Another cylinder C^3 of porus refractory material is located within cylinder C'', and is formed in two longitudinal sections and supported by metal tubes *T* which project inwardly from the ends of the converter. Arranged within the tubes *T* are a series of baffles which consist of discs *d* alternated by rings *R*, the former of which are supported by rods R'.

The end of the cylinder C are closed by plates p', which are provided with extension fingers F, Fig. 29, within the main shell, by which a firm support is provided for the end plates and tubes carried thereby. At the outer ends a pair of plates P are provided, and located near them are discharge connections d'. Near the centre of the casing C^3 there are openings O which conduct the gases to tubes T, and an outer cylinder C^4 is provided with a jacket space S^4 through which exhaust gases are circulated by means of inlet i and outlet O'.

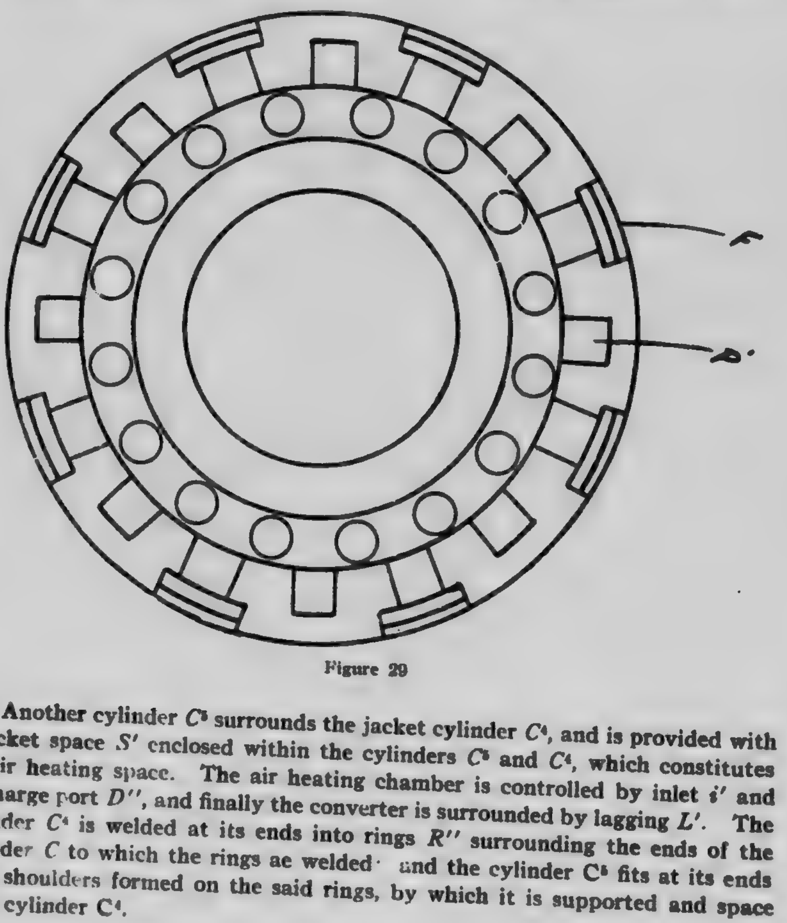

Figure 29

Another cylinder C^5 surrounds the jacket cylinder C^4, and is provided with a jacket space S' enclosed within the cylinders C^5 and C^4, which constitutes an air heating space. The air heating chamber is controlled by inlet i' and discharge port D'', and finally the converter is surrounded by lagging L'. The cylinder C^4 is welded at its ends into rings R'' surrounding the ends of the cylinder C to which the rings ae welded· and the cylinder C^5 fits at its ends over shoulders formed on the said rings, by which it is supported and space from cylinder C^4.

In the production of gas from the converter a circulation of hot exhaust gases is affected through the jacket S, and a mixture of air and oil is admitted through the connections C', which produces an incomplete combustion within the converter. The stream of oil and air entering at C' impinges in the first instance on cylinder C'' and enters the space between cylinders C'' and C^3, and imparts heat thereto by the partial combustion. As previously stated, the cylinder C'' is made of porous refractory material, and when the gas entering at C' impinges upon the cylinder, the oil enters the pores of the material, which has been raised to a high temperature by the partial combustion, and finally escapes from it as a gas or vapor. The hydrocarbon vapor thus produced then passes around the ends of the cylinder C' and into the space between C'' and C^3, and thence through opening O into tubes T, and pass through the baffles therein to discharge connections d'.

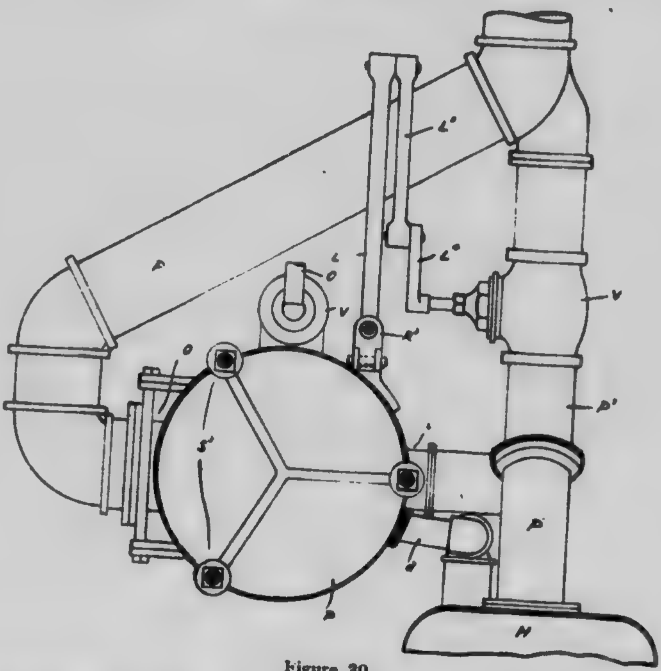

Figure 30

The partial combustion that takes place within the converter maintains a high temperature, and in order to prevent the converter from becoming too hot, means are provided by which the supply of exhaust gases passing through jacket S may be reduced automatically. This is effected by providing a thermostat, of which one member is in the converter and the other member, which constitutes a rod R^3, Figs. 30 and 31, is secured at one end to one of the rings R'' of the converter, and the other end to a pivoted multiplying lever L''. The said lever is pivoted to the other end of the ring R'', and is itself connected by a link L^3 to an operating lever L^4 of a valve V in a by-pass connection to the pipe supplying exhaust gases to the converter.

In Fig. 30 the general arrangement of a converter is shown in connection with a gas engine, of which H is the cylinder head of the engine, and P' the exhaust pipe. The pipe P' is connected by pipe i which leads to the inlet of the jacket S, and on traversing the said jacket, the gases are discharged from the connection O' to pipe P''. A connection P^3 on which is located the valve V is adapted to by-pass the gases in a greater or less extent according to the relative position of the valve V, and thereby control the flow of gases through the jacket accordingly. When the temperature of the converter is raised too high, a corresponding expansion takes place and a movement is imparted to the rod R^3 in relation to it, and the said movement is transmitted by the link motion to the valve V, and actuates it for passing the exhaust gases to a greater or less extent.

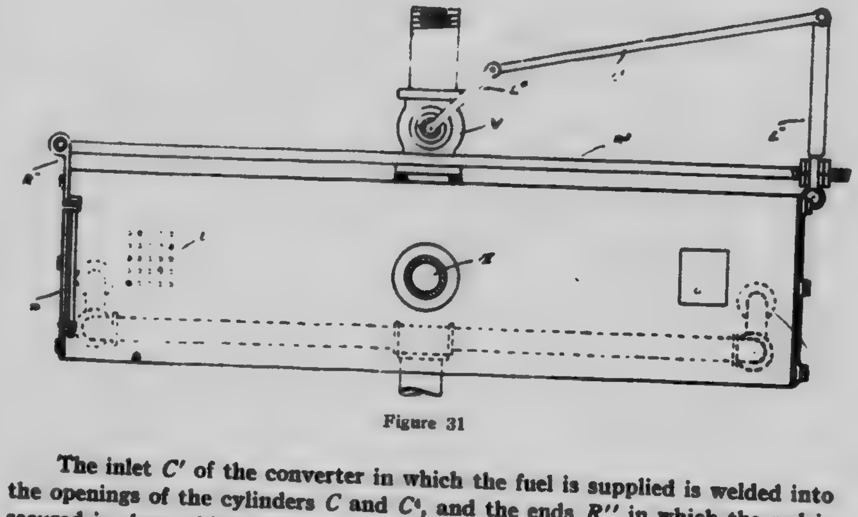

Figure 31

The inlet C' of the converter in which the fuel is supplied is welded into the openings of the cylinders C and C^4, and the ends R'' in which the rod is secured is also welded to the cylinders C and C^4. The inlet and outlet connections i and O' for the exhaust gases are welded into openings in cylinder C^5, and the discharge connections d' extend into passage P^4 formed in the end plates P' which communicates through registering openings with the interior of the said pipes; stuffing boxes S'' being provided to ensure a gas tight joint. The end plates P are hinged to the body of the converter and are held in position by studs S^3, and their arrangement is such that by unscrewing the studs, the end plates may be swung on one side and thereby expose the plates P'. These pieces can be pulled out for inspection and renewal, and also the half length of the tube T with porous cylinder C^3 and baffles d' and R, which are mounted on the said pieces. The inspection of the gas passages alone can be made without withdrawing the tubes by means of a series of sight holes H' which are normally closed with plugs.

The mixture of oil and heated air is supplied to the converter through an automatic mixing valve V' which comprises a casing C^4, which is connected to the air inlet of the converter and to the oil supply O''. Within the casing there is a sliding piston valve adapted to move longitudinally across the air inlet ports thereof, and is connected to a hollow valve stem V'' passing through a guide in the left hand of the casing. The stem V'' is provided outside the casing with a spring S^4 which tends to keep the valve in a nearly closed position. An air admission duct D^3 communicates with the oil supply, and is provided with a needle valve V^3, the stem of which is within the main valve stem V'', and is operatively connected to the said stem at its outer ends by nuts N. The oil supply O'' is provided with a plurality of ports, and the stem of the needle valve constitutes a piston adapted to travel over the orifices of the ports so as to affect their opening according to position. The operation of the valve is in relation to the demands of the engine, and as the suction increases the sliding valve moves to the left and opens both air and oil ports wider, which increases the supply. When the suction decreases the spring brings the valve back to the right and reduces the supply.

THEORY OF PRODUCER GAS: In the preceding chapters the gases referred to are chiefly used for commercial distribution, although they are occasionally used as a source of power for internal combustion engines, or other industrial purposes. When gaseous power, however, is desired on a large scale, it is usually more economical to install and operate special apparatus for the generation of weaker gases specially adapted for their purposes.

The gases employed consist of carbon monoxide and hydrogen diluted with nitrogen, and they are generated from a direct fired furnace or producer, by reason of which they are frequently called *producer gases*. In this process a bed of fuel is placed on the grate of the producer, and a volume of air is passed through the fire, either by suction or from a blowing plant. This produces combustion of the fuel in the lower part of the bed, with the subsequent evolution of heat therein. The burning gases on passing up the fuel causes hydrocarbons to distill off, and simultaneously causes the carbon dioxide produced in the lower part of the fire to be reduced to carbon monoxide in the excess of carbon. Under these conditions the gases arising from the bed of fuel consists theoretically of hydrocarbon, carbon monoxide and nitrogen, which constitutes four-fifths of the atmospheric air. It is, however common practice to admit steam beneath the bed of fuel, by which water gas is generated, and at the same time the fuel is kept from becoming overheated in the lower zone.

The composition of producer gases vary, of course, with the nature of the fuel used, and when coke or anthracite coal is used, the constituents of the fuel is chiefly carbon, which results in the producer gas being a mixture of carbon monoxide and nitrogen. Assuming that the atmospheric air beneath the grate consists of one volume of oxygen to four volumes of nitrogen, and the oxygen of the air combines with the carbon of the fuel to form carbon dioxide, as follows $C+O_2=CO_2$, the composition of the gas in the lowest zone of the fuel bed is:

$$CO_2 \text{ (1 volume)} + N_2 \text{ (4 volumes)}.$$

On passing up the fuel the carbon dioxide is reduced to carbon monoxide, as follows: $CO_2+C=2\ CO$, which makes the composition of the gas at the top of the fuel bed as:

$$CO \text{ (2 volumes)} + N_2 \text{ (4 volumes)}.$$

Under these conditions the producer gas consists of approximately 33 per cent. carbon monoxide and 67 per cent. nitrogen.

If steam is also admitted beneath the grate, water gas is formed according to the reaction $C+H_2O=CO+H_2$, which has the effect of changing the percentage of CO by decreasing the percentage of nitrogen. In view of the fact that the heating value of hydrogen is comparatively great, whilst nitrogen has no heating value, it is evident that by decompositing steam also, the power of the mixture is substantially increased.

When bituminous coals are used a large proportion of hydrocarbons are distilled off in addition to the above reactions, which increases the quality of the gas considerably, but, in general, it is more economical to utilize fuels high in carbon and generate gases of lower calorific value. It may be stated, however, that with carbon fuels such as anthracite or coke, there is usually a small percentage of hydrocarbons distilled off, and an approximate analysis of good gas with these fuels will be:

Carbon Monoxide (CO)	30.50	per cent.
Hydrogen (H_2)	9.80	"
Methane (CH_4)	3.20	"
Nitrogen (N_2)	54.50	"
Carbon Dioxide (CO_2)	2.00	"

The employment of producer gases for power purposes has been repeatedly proven to be the most efficient method, and in good practice it is customary to obtain *one-brake-horse-power-hour* at the expense of 1.05 pounds of fuel. It is found that fuels high in carbon and low in volatile matter are the most suitable for use in internal combustion engines, as the final product is cleaner and more uniform. In using fuels with a high percentage of volatile matter, the production is somewhat uneven, as the hydrocarbon in a fresh charge of fuel will distill off immediately the temperature of the charge is high enough, which has the effect of producing a usually rich gas at certain periods. These fuels have also the disadvantages of producing tar and lampblack, and thereby causing stoppages and reducing the efficiency of the gas engine by excessive carbon deposits. The use of bituminous fuels, however, are desirable under favourable conditions owing to their low initial cost, and many attempts of improvement in plant design are being made so that these fuels may be efficiently used in substitution of fuels high in carbon.

SUCTION GAS PRODUCER: In this class of producer the air and steam is drawn through the fire by the stroke of the gas engine, or by a centrifugal fan or pump when the gases are needed for other industrial purposes. In connection with the suction gas producer, it is usual to employ some form of condenser and scrubber to clean the gases before entering the engine, and the condenser has been frequently arranged so that it is adapted to pre-heat the air previous to entering the producer, whilst in other forms it is adapted to superheat water for the generation of steam. In either of these cases the principle is the same in that the air or water is passed around pipes whilst the hot gases pass through them so that the heat absorbed from the gases is taken up by the circulating fluid.

A development of the latter type which claims to generate the necessary amount of steam for the producer by the cooling system entirely is shown in Fig. 32 in which *P* is the gas producer, and is provided with a primary water heater *H*, an air inlet *A*, and a gas outlet *O*. A constant supply of water to the primary heater is provided at *W*, and a constant steam supply is admitted to the producer by way of *S* and air inlet *A*. The outlet *O* conducts the gases from the producer to a vertical boiler of the multitubular type *B*, from which they pass through outlet pipe *O'* to secondary water heater *H'*; thence through pipe *O''* to scrubber *S'*, and to the gas engine *E* for consumption.

The primary water heater *H* is connected to the secondary water heater *H'* by way of pipe p' and pump p''; and the secondary water heater is connected to steam boiler through pipe p^3 and pump p^4. The live steam is conducted to producer *P* through piping p^5, and also to steam engine *E'* which serves to operate a fuel conveyer when there is a surplus of steam.

The generation of producer gas according to this apparatus is as follows: The producer is kept at a uniform depth by charging at fixed periods, and the

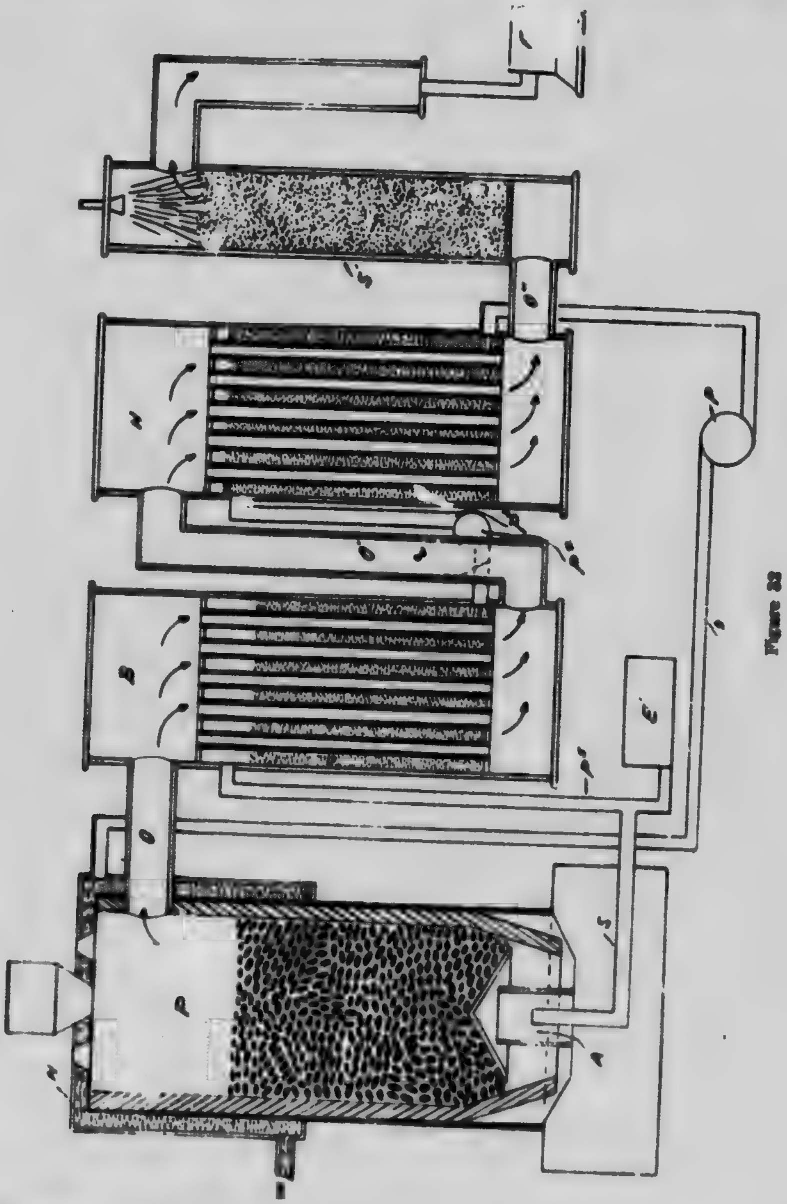

Figure 22

air passing through pipe *A* is met by a jet of live steam from *S* which passes up the fuel and is decomposed according to the reactions previously referred to. The hot gases then pass through the outlet O and through tubes in boiler B where they give up the greater portion of sensible heat to the water circulating around the tubes. On leaving the boiler the gases pass through the secondary water heater where the remaining heat is given up, after which they pass to the scrubber S' for the removal of solid matter previous to entering the gas engine. The water for steam raising receives its primary heat in the jacket H, from which it is conducted to the secondary heater H', where the temperature is raised almost to the boiling point. The hot water is then transferred by the pump p^4 to boiler B where the temperature is further raised until live steam is given off to be subsequently used in the producer.

In this process it is claimed that a saving of 5 or 6 per cent. is effected in fuel by utilizing sensible heat from the gases for steam raising, than by allowing the gases to be cooled by air, and thereby a corresponding reduction of fuel per brake-horse-power-hour.

MARINE GAS PRODUCER: A modification of the previous arrangement is shown in Figs. 33 and 34, the object of which is to centralize the plant on one common foundation so that the process is efficiently controlled in a limited space. This apparatus is specially adapted for the generation of gases for internal combustion engines for marine propulsion, where space is an important factor, and the following description will have reference thereto:

The producer furnace P is extended vertically to form a chamber C wherein the coking of bituminous coals takes place. In the top portion of the chamber C there is provided a combustion space S from the crown of which the tubes T pass through in a vertical plane to the smoke box B. The top of the producer is conical in shape as at p', and a short plate p'' is suspended within the conical portions, so that an annular space S' is formed. From these spaces a series of flues F are projected and pass through water heater W into a gas belt or reservoir R.

The primary air is admitted to the producer through inlet A beneath the grate bars G which is formed in steps and is removable. The primary air supply is by way of pipe p^3 and the secondary air is admitted through conduit C', and a series of nozzles N just below the top level of the fuel in the coking chamber. Steam is passed from the boiler by way of pipe p^4 which is communicated with the producer through valve V and air pipe p^3. The water jacket W is in direct communication with the steam boiler and the water entering at W' is gradually raised in temperature as it is passed up the tubes T where it is converted into steam.

In the operation of this plant, the fuel is fed through the door C'' into the coking chamber, where the hydrocarbons are volatilized and burned in the combustion chamber by the air admitted through nozzles N. The products of combustion then pass up tubes T to smoke box B and thereby generate steam from the surrounding water. When the fuel in the upper chamber has been derived of its hydrocarbons the resultant coke is passed into the lower zone of the producer, from which a mixture of carbon monoxide and hydrogen is generated by the air and steam passing through the fire.

This apparatus is specially distinguished in that the whole of the producer can be used entirely to generate gases on a large scale for a number of

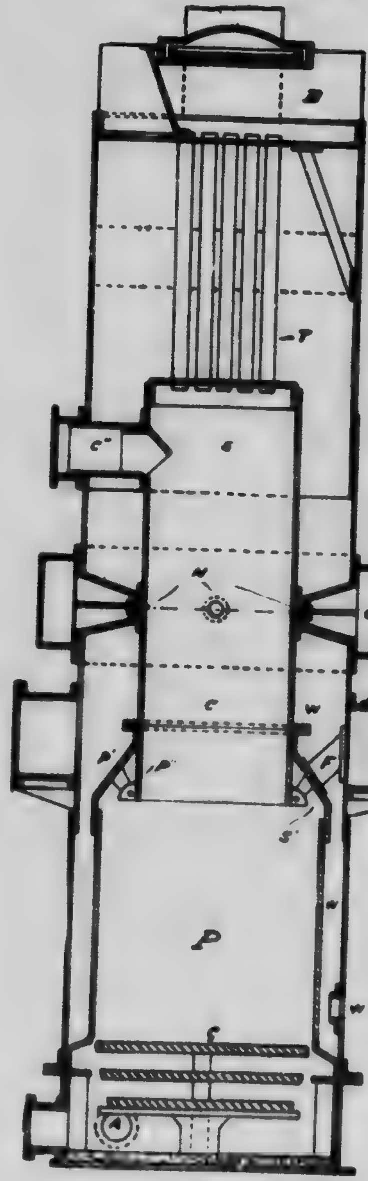

Figure 33

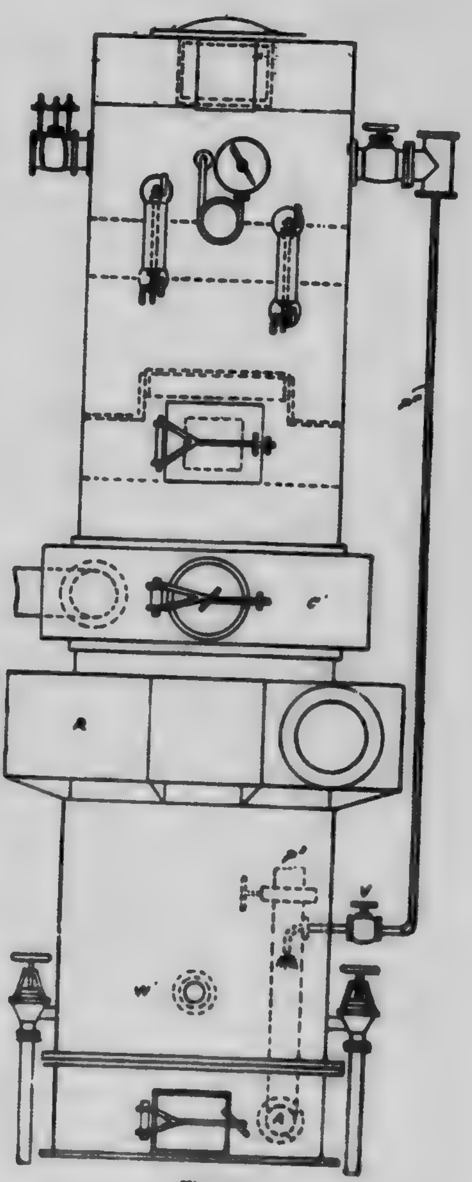

Figure 34

gas engines, or by lowering the fuel bed to a position comparatively close to the grate bars *G*, it can be used entirely as a steam boiler for the operation of steam driven mechanism usually associated with the loading and unloading of vessels when in ports. The apparatus is provided with the usual manholes and boiler mountings necessary for the efficient operation [illegible] such.

DOWN DRAFT PRODUCER: One of the most important developments in the construction and operation of gas producers was the institution of the *down draft*, by which the fire can be run for longer periods without the removal of ashes or clinker. Of this class of producer there are many designs, each of which claim some minor advantage, but for the purpose of illustration one class of apparatus will only be referred to.

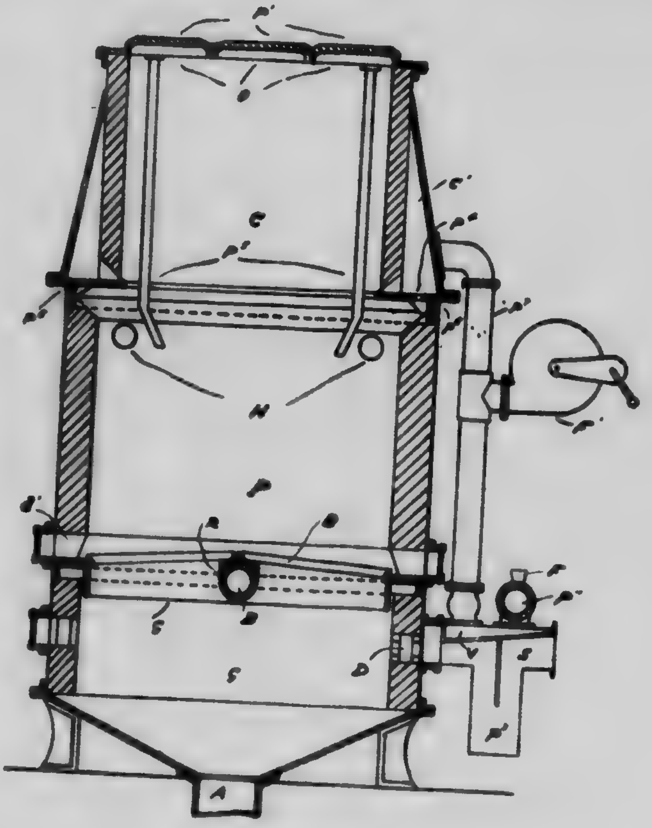

Figure 35

In this design (Figs. 35 and 36) the producer *P* is provided with a fuel charging chamber at *C*, and a gas discharge chamber at *G*. The fuel chamber is provided with fuel openings at *O*, fitted with removable covers *P'* by which the chamber is closed after each charge. At the bottom of the apparatus there is an ash discharge *A* which dips into a water lute *W*, from which the ashes passing through *B* are removed. The grate bar frame *G* has a central opening therein in the form of an ellipse, as seen in Fig. 37, the object of which reduces the liability of the frame cracking with the intense heat brought down upon it by the down draft. At a central position in each side of the fire grate, a hollow bearer *B′* is mounted to support the inner ends of the fire bars *B*, Fig. 35, which rests upon longitudinal ribs *R*. One side of the hollow bearer is open to the atmosphere, whilst the other end is connected by a pipe p'' to a vaporizer *V*, which has the effect of cooling the bearer, and subsequently heating the air passing through it to the vaporizer.

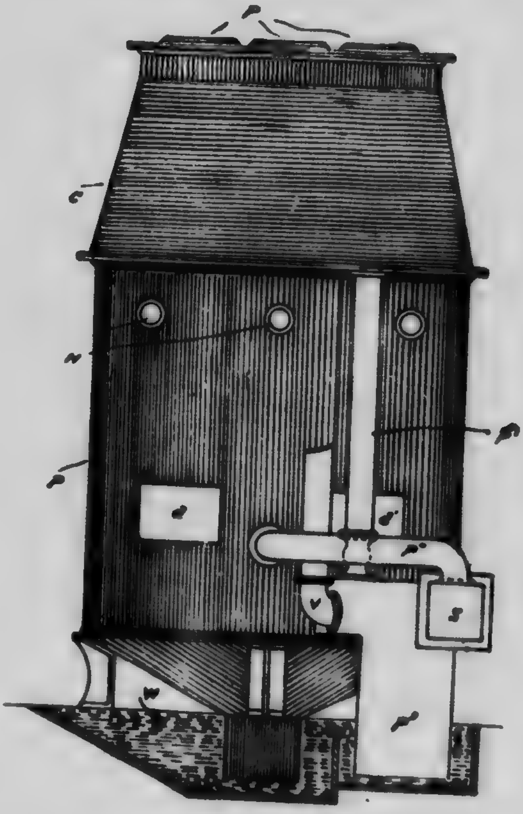

Figure 36

A seal pot *S*, arranged at the side of the apparatus, is constructed so that one end connects to a gas discharge tube *D*, and the other leads to the scrubbing and purifying plant associated with the apparatus. A baffle plate p^3 is mounted in the top portion of the seal pot to intercept the gases from chamber *G* and causes any solid matter to fall into lute *W* which is kept at a constant level with water.

The vaporizer *V* is located at the top of the seal pot and a continuous supply of water is fed to the vaporizer through funnel *F* mounted on the pipe

p'', in which flows the heated air from *B'*. The effect of the gases passing through the seal pot generates steam in the vaporizer, and this in conjunction with the heated air is drawn to an annullar chamber *C'*. This chamber has connected therewith a series of partitions p^4, the function of which is to effect an even distribution of air and steam in the producer.

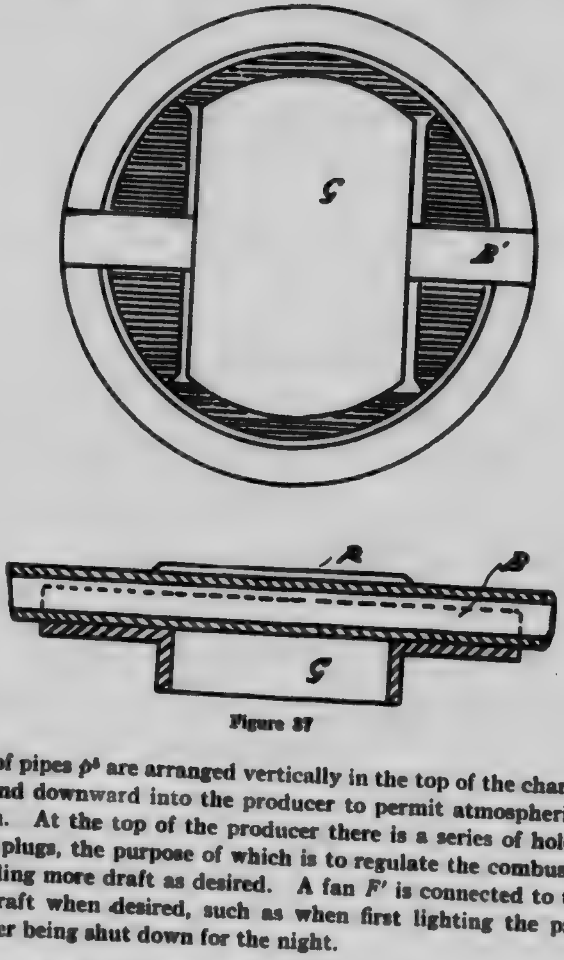

Figure 37

A series of pipes p^5 are arranged vertically in the top of the charging chamber, and extend downward into the producer to permit atmospheric air to be drawn therein. At the top of the producer there is a series of holes p^6 fitted with removal plugs, the purpose of which is to regulate the combustion of the fuel by providing more draft as desired. A fan *F'* is connected to the pipe p^7 to create a draft when desired, such as when first lighting the producer or reviving it after being shut down for the night.

The producer is provided with the necessary doors *d'* slightly above the grate bars or cleaning out ashes and clinker, and each door is fitted with poke holes for the insertion of bars without opening the doors, and at the top of the producer there is a series of sight holes *H* to ascertain how the combustion is progressing. On the seal pot *S* a vent pipe *V* is provided, and is fitted with a valve which is opened when the apparatus is shut down for the night, so as to provide an outlet for gases which may accumulate within the producer, and thereby prevent explosion.

A modification of the latter type is shown in Fig. 38, and is designed to admit air and steam in the lower part of fuel bed in addition to the primary supply, which ensures thorough and complete combustion of the fuel, so that the amount of unburnt fuel passing through the grate is comparatively small. In the down draft producer, the lower part of the fuel bed or coke zone frequently becomes dead at certain parts, and by admitting air and steam into the fuel at this point, the fuel is revived and the carbon consumed entirely for the production of gas.

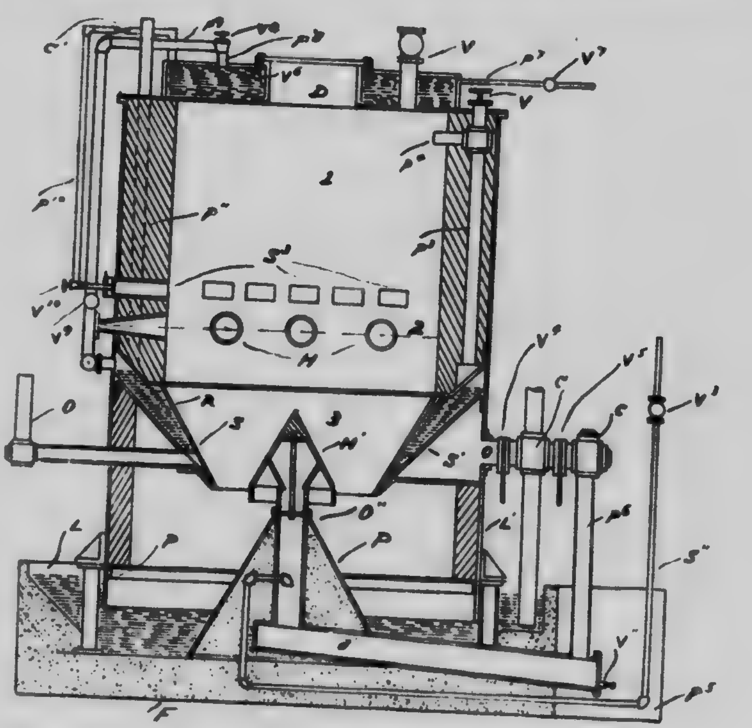

Figure 38

Referring to Fig. 38, the foundation *F* is formed with a water lute *L*, in the centre of which is placed a conical pier *P*. The producer is supported on pillars *p'* and its lower end *L'* is immersed in the liquid in the pit to form a substantial seal and prevent the escape of gases. The charging door of the producer is provided at *D*; poke holes are provided at *H*; and at the lower part of the producer the shell *S* is tapered and is surrounded by a circular shell *S'*, which, in conjunction with the former, provides a receptacle *R* for water. This constitutes the vaporizer.

A side gas off-take is located at *O* and air is introduced into the spaces above the water in the primary vaporizer *R* through a series of induction pipes *p''* embedded in the brick walls of the producer. By this means the air passing along the flues is heated, and entering the vaporizer the pre-heated air mixes with the water vapor and ascends through a series of pipes p^3 which communicate with pipes p^4 for directing the mixture to the top of the producer. A valve V serves to regulate the discharge of the mixture.

The vent pipe is located at V' to allow gases to escape when the machine is not in operation; and an overflow O' is provided for the vaporizer to ensure the level of water being kept contsant.

The main off-take O'' extends down the conical pier P and is provided with a hood H', which is also of conical shape, so that ashes will gravitate therefrom without having access to the gas off-take. The said gas pipe communicates with an inclined duct d' which is provided with a draining valve V''. The end of the duct is received in a dry pit p^5, and a series of sprinklers S' are adapted to spray water in the duct d' for cooling and purifying the gas. The sprinklers are controlled by a valve V^2, and the impurities which separate are drained off into the pit p^5. The pipe p^6, which rises from the duct, leads the gases to other scrubbing and purifying plant previous to its use for power purposes. This pipe communicates with coupling C, which, in turn, communicates with pipe O through coupling C' and valves V^3 and V^4. When the off-take pipe O'' is in use, the valve V^4 is closed and the valve V^3 is open, and the gases pass through coupling C′ for further treatment. The outlet O is provided only for emergency, and when in use the valve V^4 is open and valve V^3 closed.

Around the producer a secondary vaporizer V^6 is arranged and receives its water through pipe p^7 and valve V^7. Air is admitted to the secondary vaporizer through pipe p^8 and valve V^8, and communicating with the pipe there is another pipe p^9, which leads to the space above the water in the primary vaporizer R. A valve V^9 serves to control the pipe p^9. When the latter valve is closed and valve V^8 is open, air is admitted to the secondary vaporizer, and on closing the valve V^8 and opening valve V^9, the surplus vapor from the secondary vaporizer passes into the primary vaporizer and commingles with the vapor therein, so that the mixture rising up pipe p^3 may be augmented when necessary.

A series of secondary air and steam tuyeres S^3 opens into the interior of the producer below the level of the fuel zone 1, so as to cause reaction in the coke zone 2 of fuel that has not been completely burnt in the upper zone. The tuyeres are connected to pipe p^{10} and admit air and steam at various points around the producer, and the resultant gases pass through chamber 3 to the off-take O''. Each set of tuyeres are controlled by a cock C'', and each individual tuyere by a valve V^{10}, so that the supply of air and steam can be admitted to any one part of the fuel bed, whilst the other part is cut out according to the condition of the fire in the coke zone.

The primary vapor and air is taken from the vaporizer R and led through pipe p^3 and p^4 to the top of the fuel, and the secondary air and steam is taken from vaporizer V^6 and distributed from the tuyeres S^3, subject to the adjustment of valves V^{10}; whilst by closing valve V^8 and opening valve V^9, the surplus from secondary vaporizer passes into primary vaporizer and therefrom to the fuel in the producer.

UP-DRAFT POWER PRODUCER: In the up-draft-power-producer, as used for the generation of gases in large volumes, it is common practice to force the air into the bottom of the producer beneath the grate under the pressure of a centrifugal fan. In this practice the amount of fuel consumed per square foot of grate area is comparatively large, and the grate bars soon become coated with ashes and metallic residue from the fuel, which fuse together and form large masses of clinker. This condition produces *blow or dead holes* in the bed of the fuel, which invariably has the effect of producing irregularities in the composition of the gas produced. This has long been a serious difficulty to contend with, and many designs of moving or oscillating grates have been tried to overcome this difficulty. In general, it may be said that none have been thoroughly successful, although good progress has been made by some of the most important.

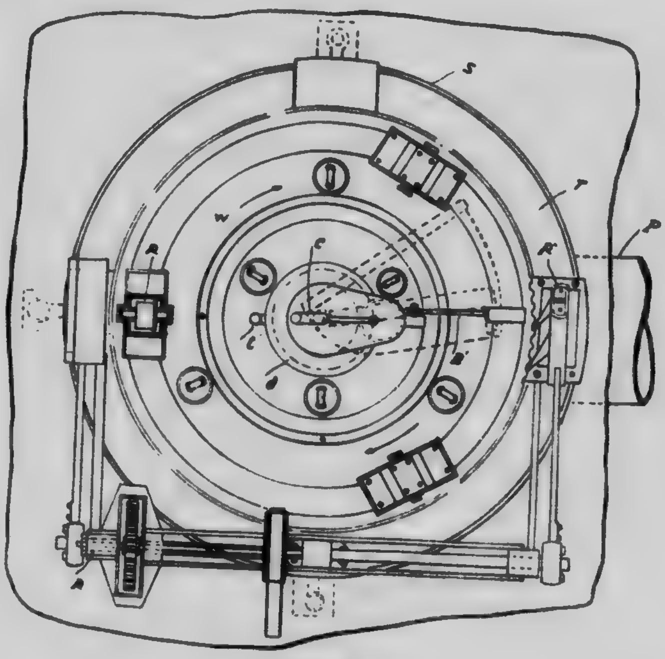

Figure 39

One of the most interesting examples of these is illustrated in Figs. 39 to 42, in which a stirring device is passed through the fuel and immediately followed by a supply of fresh fuel, so that its wake is filled and the level of the bed always maintained.

Referring to the apparatus, the shell *S*, Figs. 39 and 40, of the producer, is provided with a rotary top *T* and rests on a foundation *F*, and is provided with the usual ash pit and water lute *L*. The air and steam inlet pipe *A* is located in the centre of the furnace, and is provided with a hood *H* which is adapted to distribute the said fluids evenly under the fuel *F'*. The resultant gases are led off through pipe *P*, and the upper end of the furnace is provided with a water seal *W*.

The top of the producer is provided with a water jacket *W'* and is mounted to revolve on a vertical axis on rolls *R* through a source of power *R'*. On the top of the producer there is located a fuel hopper *H'* which is inclined so as to have its upper end concentric with the axis of the cover. The hopper is provided with a cover *C*, and projecting below it there is an annular disc *d*, which covers an annular trough *t'* surrounding the top of the hopper. The trough *t'* receives water from pipe *p'* and drains into tube *t''* which leads downwardly to the edge of the furnace, and through the water jacket *W'* into the fuel hopper *C'* to the bottom thereof, and finally up the vertical axis of the cover *T*, where it ends in the water seal under the baffle plate *B*. The baffle plate prevents any sediment falling into the pipe, and the disc prevents fuel from falling into the trough *t'*. The fuel hopper is provided with a bell bottom *B'* for feeding the chamber *C'* and is placed on one side of the furnace so that fuel will follow the agitator *t''* as it rotates and evenly distribute it over

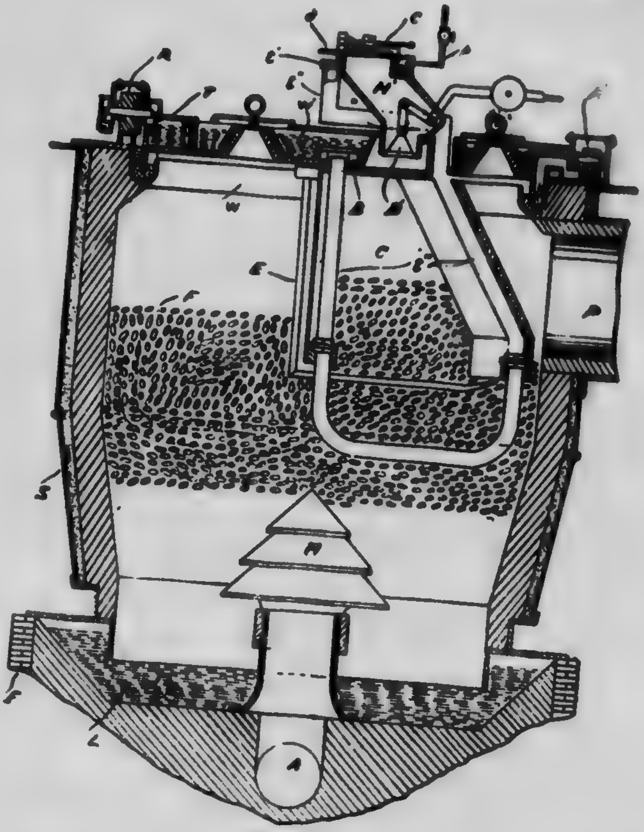

Figure 40

the surface. The lower edge E is bevelled on its rear side, and is upwardly turned near its outer end, so as to make a thicker fire near the wall of the furnace to prevent escape of steam and air at this point where dead holes are frequently formed.

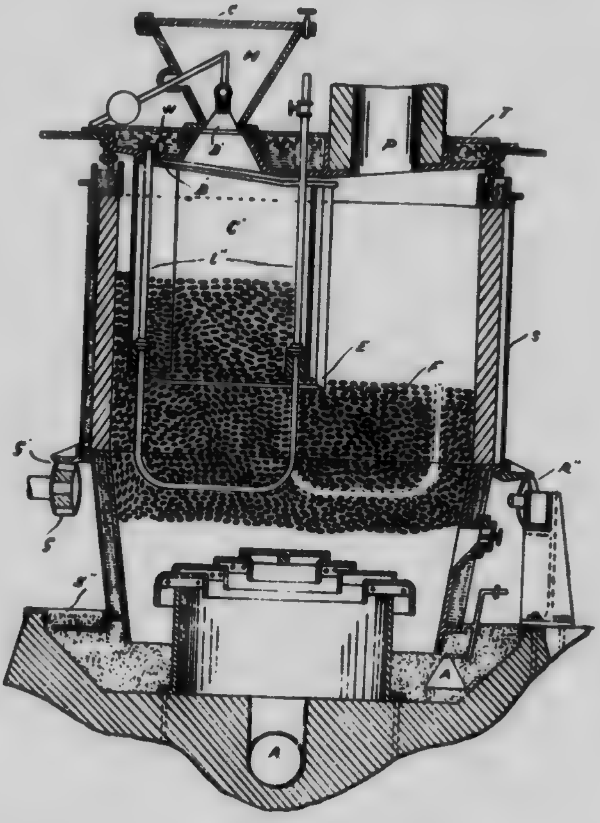

Figure 41

The apparatus shown in Figs. 41 and 42 is designed to effect the same results, and the operation is slightly different in that the shell S' rotates while the top T' remains stationary. According to this design the body runs on rollers R'' and is driven by bevel gearing G and G', and carries the fuel bed again against the agitator t'' and fuel chamber C'. The body also carries an ash plow A' and a shelf S'' which is adapted to catch the ashes raised higher than the plow from which they fall into an ash hopper for removal. The introduction of steam and air is the same as in the previous design and also the off-take of gas.

If the operation of the apparatus according to Figs. 39 and 40 is followed, it is seen that the fuel is supplied in the usual manner through the hopper H' and bell B' into the interior of the chamber C', and that the top or cover is

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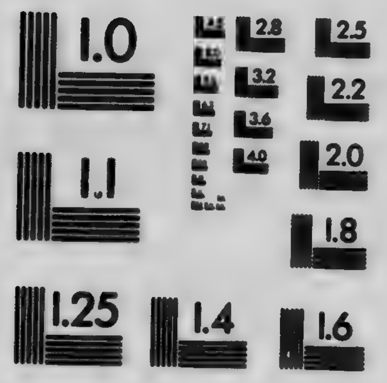

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rotated on its axis at a slow rate of speed, whilst water flows into the jacket *W′* and through agitator *t″* and fuel chamber to the bottom of the fuel bed. By this movement the blow or dead holes are distributed by the slicing action of the agitator which simultaneously provides a supply of fresh fuel and maintains a constant level on the fuel bed; and thus improves the quality and uniformity of the gaseous mixture escaping therefrom.

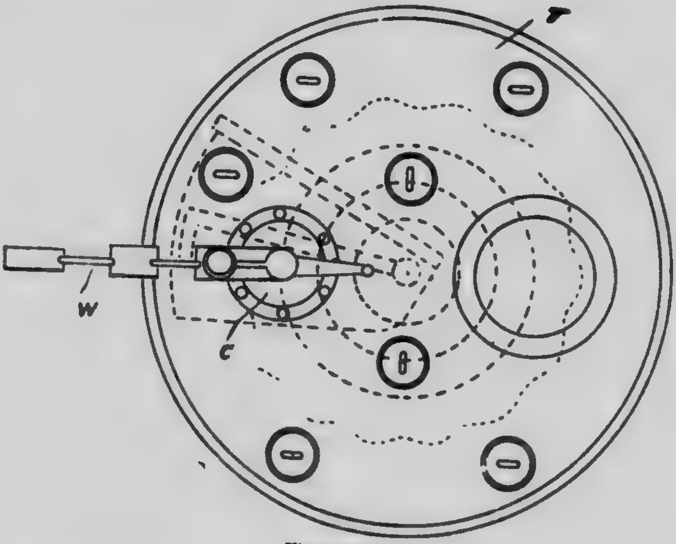


Figure 42

PEAT GAS: The use of peat for the generation of power gases has not developed as fast as the conditions justify. This is, no doubt, due to the absence of practical machinery for the use of this material on a scale that is comparatively smaller than is needed for a briquetting plant. With the development of peat bogs on a large scale there is every possibility of employing peat in suction gas producer for the generation of electrical power. Incidentally, the use of peat should be of special interest, as its utilization simultaneously converts the hitherto peat-bog into land which may be put to fertile use. The greatest developments of peat gas producers have been made by the MOND GAS CORPORATION, whose plants are designed specially for the recovery of by-products. They have been built in various sizes, one of the largest of which is for the generation of electrical power to the extent of 3,000 indicated horsepower daily. A peat-gas-by-product installation should be of special interest to an agricultural enterprize, as the chief by-product is sulphate of ammonia, which is a valuable fertilizer.

The composition of peat is given in Table 1, page 8, and is similar to coal with the exception that it contains from 40 to 60 per cent of moisture, which limits its use to the vicinity of its production. In the use of this fuel for briquet manufacture the moisture is eliminated by mechanical means, as illustrated in *Fuel Briquets, Chapter 7*, but for use in a suction gas producer, the raw peat can be used without being previously subjected to drying treatment.

As previously stated, the Mond Gas Producers have, no doubt, received the greatest recognition, but as this work is not intended to treat by-products, an efficient design, of which the writer is acquainted, is illustrated in Fig. 43.

The producer is shown at *P*, and has a hearth *H* of ordinary construction. A fuel hopper *H'* leads to tube *T* in the centre of which is located a worm feed device *W*. The worm is driven by means of bevel gearing *G* and *G'*, the last element of which is driven by the shaft *S*. The lower end of the feed tube *T* communicates with a gas-tight hopper *H''*, which is operated by means of a handle, and an air supply *A* leads from the end of the tube to air pump *A'*, and to the pipe p' which delivers air to the hearth *H*. The pipe *A* is provided with regulating valve *V*, and communicating with this pipe there is another pipe p'', which opens to the atmosphere through regulating valve *V'* for the admission of secondary air, if desired.

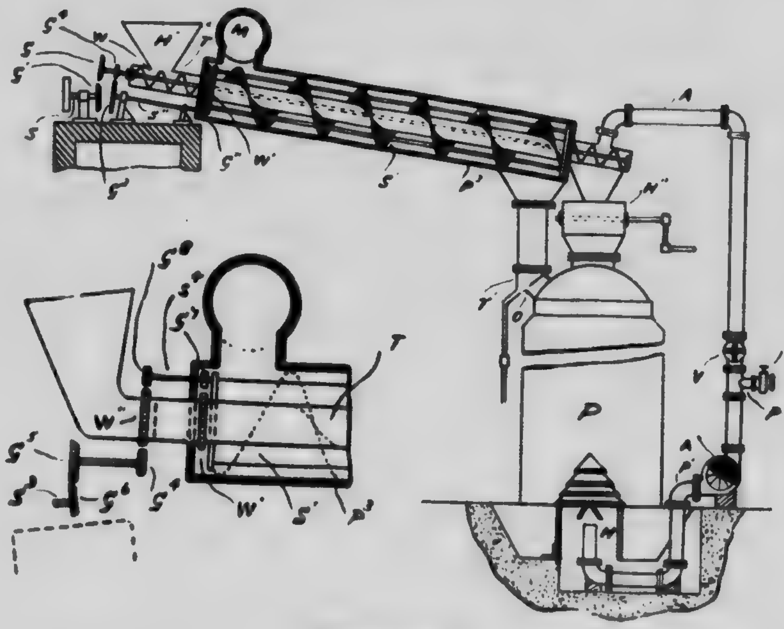


Figure 43 and 44

The outlet for the producer gas is located at *O* and leads to a pipe p^3 concentric with the feed tube *T*, and communicates with main *M*. In the pipe p^3 there is a scraper *S'* which is revolved by means of a wheel *W'* gearing with a pinion G^4 on the shaft *S''*, upon which another wheel G^3 gears with a pinion G^4 on the shaft of the worm.

In this plant the air is first drawn through the incoming fuel in the feed tube *T* and passes through the pipes *A* and p' to the hearth *H*. The hot gases are driven through the outlet *O*, and on passing through the pipe p^3, they impart a comparatively large proportion of their heat to the incoming fuel, which evaporates the moisture and finally produces steam or water vapor. The steam is carried along with the air on pipe A, the supply of which is regulated by valve V, whilst secondary air is provided, if necessary, through valve V'. The scraper S' is adapted to remove any tarry matter which is liable to be deposited in the pipe p^3, and carries such to a trap T' from which it is drained by a valve.

A slight modification of the mechanism associated with this apparatus is shown in Fig. 44, in which the feed tube T is rotated by means of a wheel W'' gearing with a pinion G^5 on the shaft of which is also a bevel wheel G^5 gearing another bevel wheel G^6 on a driven shaft S^3. The scraper S' is revolved by means of a wheel W' gearing with a pinion G^7 on the shaft S^4, upon which is another wheel G^8 gearing with the wheel W''.

The same results are obtained in the latter design, and from the foregoing it is evident that the fuel is carried to the charging hopper by means of a worm device revolving in an inclined tube, which is surrounded by an outer tube carrying hot gases from the producer; the latter of which are adapted to give heat to the incoming fuel, and generate steam or water vapor therefrom. The steam and air are drawn from the tube by a pump and forced through the fuel in the producer in proportions according to the relative positions of the primary and secondary air valves.

WOOD GAS: In secluded districts on the continent of Europe and Western Australia it is known to generate producer gases for use in internal combustion engines from wood and shavings. The generation of gases from this matter is impracticable where coal or like fuels can be obtained, but in the districts referred to, where railroads do not penetrate, and the supply of wood is plentiful, it is more economical.

The operation of a producer using wood fuel is practically the same as when using hard fuels containing more carbon, but the apparatus usually contains some special design of fuel hopper for constant charging, owing to the comparatively large volume of fuel required.

One of the most simple and efficient of these arrangements is illustrated in Figs. 45 and 46, and is adapted to feed large logs of wood, or shavings and sawdust as required. Referring to the apparatus, the fuel or stoking chamber C is located on the top of the producer chamber C' which is constructed with a steel shell S and firebrick lining L as in the usual manner. The fuel opening F is fitted with a removable cover C'', through which the fuel is fed when logs of wood are used. When it is desired to use shavings or sawdust in the producer, a cylindrical basket-like chute is inserted in the fuel chamber and is adapted to distribute the shavings evenly and prevent them from packing. The chute C^3, is made slightly conical so that its lower part p which is constructed of perforated plate, opens at the bottom; whilst the portion p' is furnished with a flange or ring R adapted to bear on the flange of the fuel opening F and is held in position thereto by a joint J arranged between the aforesaid flange and the door or cover C''. This enables the chute to be easily removed when it is desired to feed logs of wood into the producer.

The apparatus is operated by a down-draft by the suction of the gas engine, and the zone of combustion rises in the perforated plate of the chute by the admission of air therein. The admission of superheated steam is effected from the chamber *S′* which is connected by a pipe p'' to a separate flash vaporizer. A series of holes *H* formed in the top of the producer provides for the admission of steam, and a series of holes *H′* fitted with removable plugs serve to regulate the admission of air. When the fuel used consists of large logs of wood, the chute is removed and the fuel fed through opening *F* and arranged vertically in the chamber above the producer, when the bottom ends gradually become charred and the logs fall over and become totally consumed in the producer.

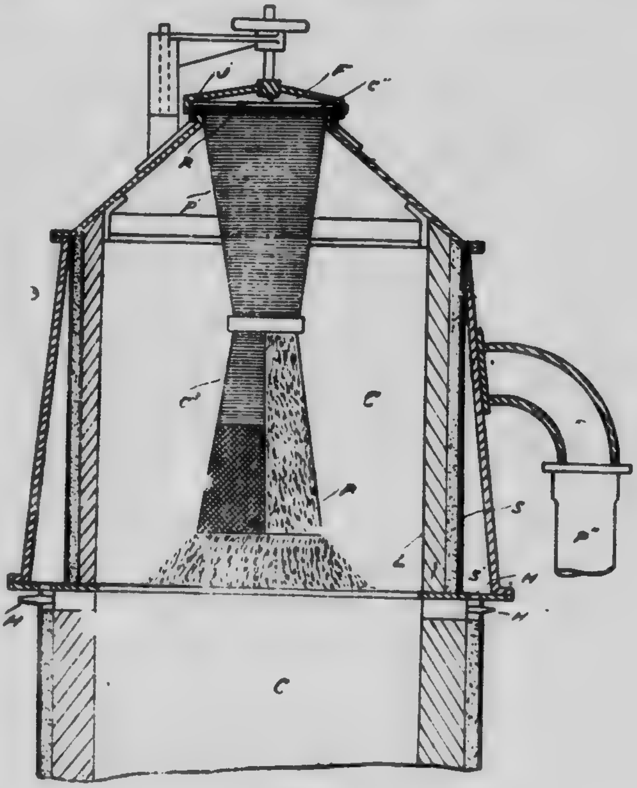


Figure 45

LIGNITE GAS PRODUCER: The use of lignite for the generation of producer gas is known in certain localities where it is readily available, but under ordinary conditions it is impracticable, owing to its large percentage of moisture and mineral matter. The specific gravity of lignite may be from 0.5 to 1.25, and it may contain from 50 per cent. of carbon with a small percentage of hydrocarbon. It is very brittle; breaks easily in transportation; absorbs moisture from the air; and, consequently, is of little value unless used in the vicinity of its production.

One of the most efficient designs of apparatus that has been used for the production of gas from lignite is illustrated in Fig. 47. In this apparatus a series of vertical retorts are supported by heavy walls *W*, on the top of which is mounted a hopper *H*, having a series of angle irons *A* arranged across it.

The lignite is charged into the hopper in a comminuted state and descends by gravity pass the angle irons into a series of tubes *T* arranged vertically within the plant. On the upper ends of the tubes there is mounted a sheet *S* which completely closes the top of the chamber. The tubes are closed in at the bottom by a second sheet *S'* and a pair of baffles *B* are provided between the two sheets so that the gases circulating around the tubes take a wave-like path and distribute heat evenly thereon. A by-pass *B'* is provided in the wall of the structure and provides communication with the combustion chamber of the plant for admission of burning gases therefrom. The carbonizing chamber is located between the sheets *S''* and *S'''* at the top and bottom, respectively, in which a series of retorts *R* are vertically arranged therein. A pair of baffles *B''* serve to distribute the

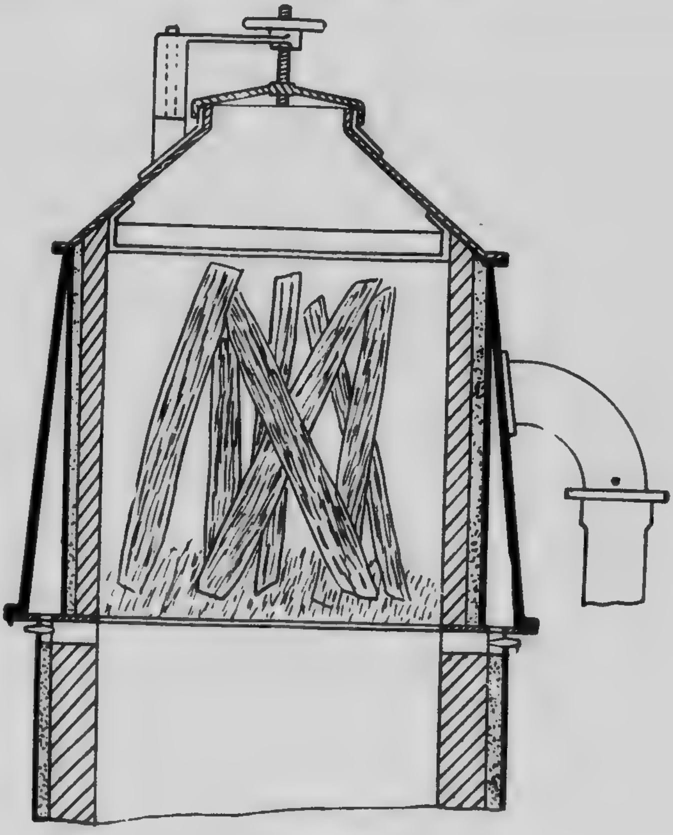


Figure 46

heat as in the upper chamber. A gas burner is located in the opening at B^3, and the gas producer P has a conduit C leading therefrom, through which the producer gases are withdrawn. A removable stepped grate G supports the fuel in the bottom of the producer.

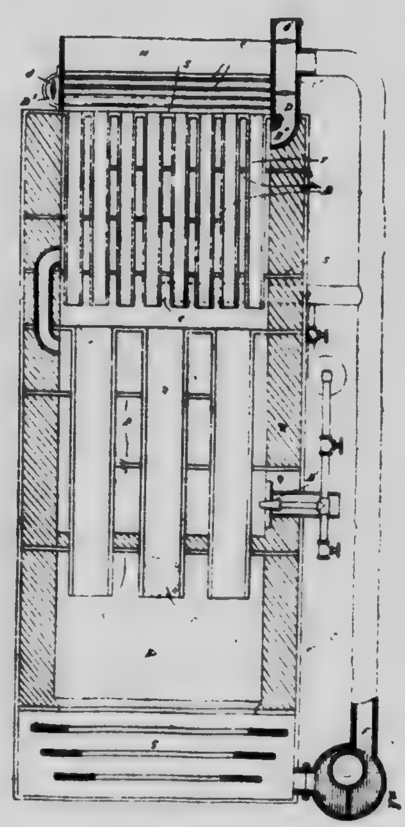


Figure 47

A blowing fan F communicates with the lower part of the gas producer, and a conduit C' connects the blower with the upper end of the top section. A by-pass B^4 is located below the upper flue sheet S and communicates with a short stack S^4, within which are provided a pair of dampers D and d'. On the opposite side of the hopper a by-pass B^5 is provided with a damper d'', and when D is closed the damper d'' is opened. In the centre of the plant a conduit C'' is located above the carbonizing section, through which the volatile matter from the fuel is withdrawn.

The top section is adapted to remove the entrained or occluded moisture from the lignite, and the middle section serves to distill off the volatile constituents previous to the fuel entering the lower section or producer proper for the generation of gases from the carbon residue according to the known reaction.

In the operation of the plant the lignite is deposited in the hopper and passes by the angle irons into the tubes T. The combustible gases for heating the upper and middle chambers entering at B^3 are ignited and the products of combustion pass around the retorts and through by-pass B′ for the subsequent heating of the tubes T. This serves to remove the moisture from the lignite and the dired product passes into the retorts, where the volatile matter is distilled, and the vapors drawn off through conduit C''. The fuel on passing through the retorts is raised to a state of incandescence, and is deposited in the lower chamber P, where it is converted into carbon monoxide and hydrogen by passing carbon dioxide and steam through it by means of the fan F. The carbon dioxide and steam is produced by the combustion of gases around the retorts and the water vapor driven from the lignite; and is drawn off from the upper chamber through pipe C' by the suction of the fan. The resultant producer gas is drawn from the plant through pipe C for purification previous to its use for power purposes.

COKE

GENERAL REVIEW: The use of coke as a fuel for metallurgical or other industrial purposes has made remarkable progress during recent years, and it is believed that in course of time it will entirely displace coal for direct-fired furnaces. The principal reasons for this belief is because it contains very little volatile matter, and can therefore be completely burned within the furnace without the formation of smoke or loss of combustible matter. Its general progress may be seen from the following table, which represents U. S. A. practice, and is officially compiled by the U. S. Geological Survey:

TABLE 12.

U-S COKE REPORT

Year	Coke Ovens	Tons Coke Used	Tons Coke Produced
1880	12,372	5,227,741	3,338,300
1885	20,116	8,071,126	5,106,696
1890	37,158	18,005,209	11,508,021
1895	45,565	20,848,323	13,333,371
1900	58,494	32,113,553	20,553,348
1905	87,564	49,530,677	32,231,120
1910	100,440	63,008,327	41,708,810

The *value* of coke is frequently standardized by the percentage of carbon, and its value according to this standard is greatly influenced by the methods of manufacture. The presence of volatile matter in coke is due to incomplete carbonization in the ovens and the more concentrated cokes are obtained by higher heats and longer carbonizing periods.

In the production of *gas-coke,* the manufacture of the gas is the first importance, and the coke is a secondary product. It is produced by allowing gas-coals ain in a closed retort at a temperature which is just sufficiently high to off the illuminating gases. It remains in the retort for four, six or eight only according to varying conditions, and is consequently much softer than -coke, which is occasionally carbonized as high as 72 hours.

The manufacture of *oven-coke* as a commercial product originated from the increasing demand for a smokeless fuel, and the first important developments were made with the introduction of the bee-hive ovens. The production of oven coke has increased very rapidly during recent years, and the methods of carbonization are becoming more scientific each year. That these scientific methods are the means by which the coke industry is growing is undisputable. The improvements made are chiefly in the methods of combustion so as to effect uniform and economical heating of the oven, and it is believed by the writer that a study of this subject will be of value to all interested in a grade of coke.

PHYSICAL PROPERTIES: The appearance of coke is familiar to all, in that it is a hard, cellular, lustrous body; consists chiefly of carbon; and burns with comparatively little smoke or flame. The properties desired for industrial use is hardness, good cellular structure, purity and regularity.

The *hardness and strength* of coke are important factors in furnace practice, as the soft cokes are more readily dissolved by carbon dioxide, and consequently produce more carbon monoxide at the top of the furnace, and thus causes combustible matter to pass up the stack. Whilst the strength of a coke bears a close relation to its hardness, it may also be said to be a distinct property. For instance, some cokes, though hard, are very brittle, and consequently break easily in transportation; whilst occasionally a soft coke may be strong and still reduce carbon dioxide more readily than a hard coke. The consideration of these properties are necessary for the economical operation of any one particular process, and a strong coke is desirable in large furnaces as used in metalurgical practice where a great burden is exerted upon it. A weak coke whilst being suitable for certain purposes, is undesirable in the latter class of furnace, in that it is too easily reduced, and breaks easily in transportation, making a comparatively large amount of small coke or breeze. The weak cokes are more suitable for steam boilers, furnaces or other places where the fuel bed is low and there is a plentiful supply of air over the top of the fuel.

In the transportation of coke from the ovens to the point of consumption it is handled (1) In railroad cars for shipment; (2) In conveyors, barrows, or transfer cars at the furnace plant; (3) In charging bins or hoppers directly over the furnace; so that it is common practice to handle at least three times, which results in a comparatively large amount of breakage in soft cokes, which may amount in extreme cases to 20 per cent. These considerations should be kept in view when deciding on the class of coke for a particular purpose.

The *cellular structure* of a coke is another important factor, and a coke which is porous and readily permeatable by gases in its course of descent is the most desirable. This qualification not only increases the surface for the combustion of the fuel, but also admits the air blast to penetrate it and thereby localize complete combustion at a zone in which it is needed. These cells are usually greater than the outside appearance indicates, and it has been computed that a coke with a good cellular structure may occupy as high as 45 per cent. of the coke space.

The porosity of a coke may be approximately ascertained by immersing in water, and comparing the weight before and after, which gives the amount of water absorbed.

Another important factor in the quality of coke is *purity*, which has reference to the respective percentages of carbon, ash, sulphur and phosphorous. As coke is a derivative from coal, the impurities bear a direct relation to the coal from which it was formed, and the percentage is somewhat larger in proportion, owing to the coke being a concentration of the coal. The chief constituent is carbon, which is the heat-giving element, and consequently the quality of a coke is rated according to the percentage of carbon contained therein. An analysis of coke from the most important coal fields of U. S. A. gave a composition according to the following table:

TABLE 13.
GRADES OF COKE FROM U. S. COALFIELDS

Coal Field	Carbon	Volatile Matter	Ash	Sulphur	Phosphuro
Alabama	83.15	2.75	14.10	1.20	.018
Connelsville	87.22	1.08	11.70	.86	.012
West Virginia	88.60	1.12	10.28	.69	.009
Pocahontas	92.30	1.20	6.50	.60	.010

The *regularity* of a coke is also a factor which is recognized to be of importance, and coking plants endeavor to maintain a standard by discarding portions of the coal vein that is high in impurities, and by efficient operation. It occasionally happens, however, that *black ends* are seen in cokes from coals which are homogeneous, and are present entirely to improper coking methods.

The manufacture of coke from coal is briefly that of driving off the volatile matter from certain classes of bituminous coals, which have properties which cause them to change their original shape, and fuse into masses of porous spongy material. The exact theory of this formation has not been thoroughly defined, but it has been claimed that it is caused by isolation of a compound known as *carbene*, $C_{22}H_{14}O_{5}$. During the period between slight and total fusion, there is a complete decomposition of the coal, and the formation of a new structure which bears no resemblance to its original form; which is claimed to be by the cohesion of the compound carbene. This theory appears to gain strength by that fact that certain coals of the non-caking class may have a similar composition to those of the caking class, and have their volatile matter driven off under similar conditions, and yet retain their original form with the exception of being charred.

BEEHIVE OVEN: These ovens originally consisted of dome-shaped chambers, in which the coal was placed in layers at the bottom, whilst air was supplied through a door in the side to support combustion of the volatile matter from the coal. At the present time the greatest portion of coke is made from some modification of this class of oven, although the *retort and by-product ovens* are claimed to be more exconomical, and are rapidly displacing the former class.

The bee-hive, however, is still installed in some plants, and is regarded by many as being productive of the best classes of coke. Its advantages over the by-product ovens may be stated as:

(1) The initial outlay of capital per unit of coke produced is considerably less.

(2) The cost of operation is comparatively small, and does not require skilled labor.

(3) The operation may be discontinued or resumed with less inconvenience or expense.

In the present form, the beehive oven is from 12 to 15 feet in diameter, and from 7 to 8 feet from the floor to the dome. It is constructed with a tunnel head *H*, Fig. 48, for charging the coal and taking off the gases, and a door *d* for the admission of air and withdrawal of coke; the door being bricked up to within about one inch from the top during operation, so that air is only admitted above the charge, and the volatile matter only burned.

The heat of combustion of the volatile matter maintains the temperature of the oven and charges are usually made very 48 or 72 hours. In the 48-hour charges the amount of coal placed in 12 foot oven is approximately 10,000 pounds, which lays in the bottom of the oven at a depth of 23 or 24 inches. In the 72-hour charges, about 12,000 pounds of coal is placed in the oven, and lays at a depth of about 27 inches.

Immediately the charge is put in, the temperature of the oven drives off the volatile matter, which is burned by the incoming air, and the combustion heats the dome which reflects the heat upon the charge, and causes coking. When the volatile matter has been driven off, the bricks in the door are removed, and a hose is turned on the coke previous to drawing. The 72-hour coke is more concentrated than the 48-hour, and is generally more suitable for blast furnaces. The weight of the coke from this class of oven is from 60 to 75 per cent. of the coal and somewhat less in volume.

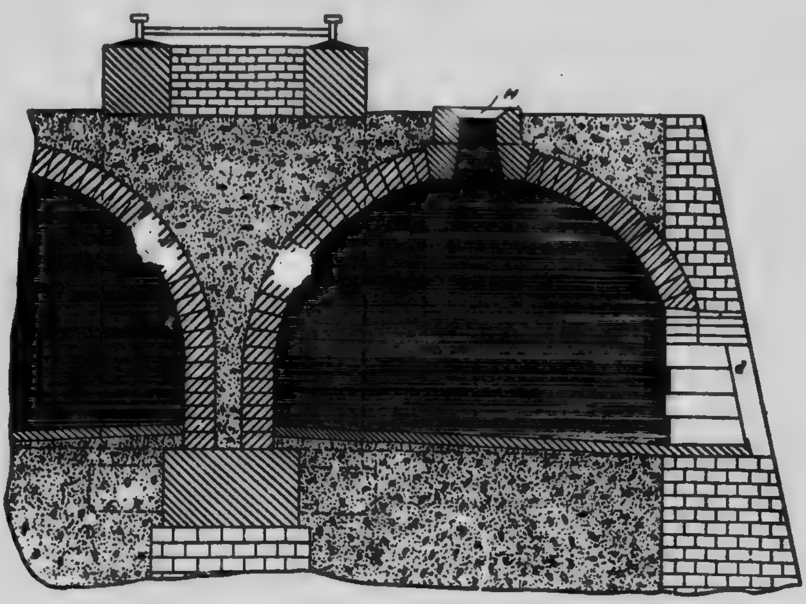


Figure 45

BY-PRODUCT OVEN: The development of coke ovens from the original beehive was first made in Europe, particularly in Germany, and the process was improved first by leading the excess of gas through combustion flues in the walls of the oven, by which the sensible heat from the burning gases were utilized to impart heat to the oven instead of being lost in the atmosphere as in the original process. It was later claimed that it [illegible] be to advantage to heat the ovens by gas alone without any combustion taking place within the oven; and that the absence of air would prevent oxidation of the coke. After some time this was modified by an apparatus in which the gases were withdrawn from the oven and passed through suitable washing or extracting apparatus for the recovery of tar and ammonia, after which the permanent gases were fed to the combustion flues for the subsequent heating of the ovens. The process has since developed in a variety of ways embodying these principles, of which the most illustrative will be described in the following pages.

The ovens of the by-product process are usually rectangular in shape and may be horizontal or inclined. The special advantage of the inclined class is that the coke can be forced from them more easily into cars for transportation. In Figs. 49 and 50 a design of the horizontal class is shown, in which the ovens *O'* are provided with charging vents *C*, into which coal is fed by means of a lurry *L* and hopper *H* which runs on a track on top of the ovens. The coke is withdrawn from vents which have removable doors *d*. An air pipe *A* having a series of tuyeres *T* is adapted to supply air to the bottom of the bed of coal in the ovens, and is controlled by a valve *V* which communicates with a pipe *p* from an air blower.

A series of pipes p' extend from the top of the ovens to provide an outlet for the gases and communicates with a large gas main *G* through valve *V'*. The blast of air is forced into the ovens by a centrifugal pump p'' which supports combustion of the coal, and the gases pass through scrubber *S* which is provided with pipes p^3 for spraying sulphate liquor upon the incoming gases. This liquor is drawn by means of a pump p^4 and forces such to the top of the scrubber, where it passes downwards while the gas passes up and out through the pipe p^5 into a rotary washer *W*, which also contains sulphate liquor.

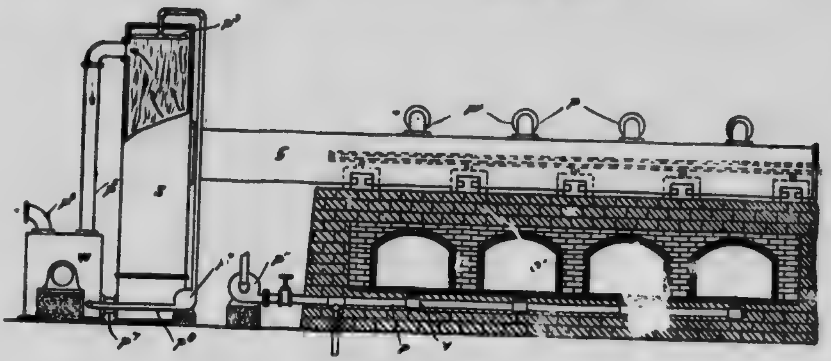


Figure 49

The action of the liquor on the gas in the scrubber is to absorb a certain amount of ammonia, the remainder of which is absorbed by the washer *S*. The purified gas leaves the washer by way of pipe p^6, and passes to a holder to be used for power or heating purposes. The liquor passing through the scrubber collects in the bottom and flows through pipe p^7 to the washer *S*, from which it is drawn by pump p^8, and re-circulates through the scrubber until it becomes concentrated when it is used for the manufacture of sulphate of ammonia. It occasionally happens that water is circulated in the washer and scrubbers instead of sulphate liquor, which results in the formation of ammoniacal liquor for the manufacture of other ammonium compounds.

In the operation of these ovens the coal is first charged through vents *C*, and the doors made secure. The combustion is then commenced by the admission of air through tuyeres *T*, after which the vents *C* are closed and the valve *V'* opened. The gases then pass through main *G* to scrubber *S* and washer *W* to a storage holder and after the volatile matter has been driven off the valve *V'* is closed and vents *C* opened to finish the carbonization of the charge to the desired condition of the coke. During this part of carbonization the air is cut off from tuyeres by valve V, and a slight amount admitted through the doors d until coking is complete. The charge is then chilled by water passing along spray pipe S' which is adjustable at S'' and is adapted to be put into the upper part of each of the ovens previous to the withdrawing of coke. The spraying device is carried along frame F which runs on a track t' along the whole length of the bench.

HEATING RETORT OVENS: The most important factor in the economical operation of coke ovens is the efficiency of the heating system, and it has been claimed that the beehive ovens are more economical than the *retort oven* owing to there being no loss of heat by radiation by the internal combustion of the fuel direct within the oven. It is evident, however, that the retort oven possesses many advantages over the beehive and promises to become more popular with improvements in the heating ssytem, which combine efficiency with economy.

In this system the whole of the gas distilled in the oven may be used for domestic and industrial purposes, whilst the heating system is affected from a producer adapted to generate gases from inferior grades of fuel.

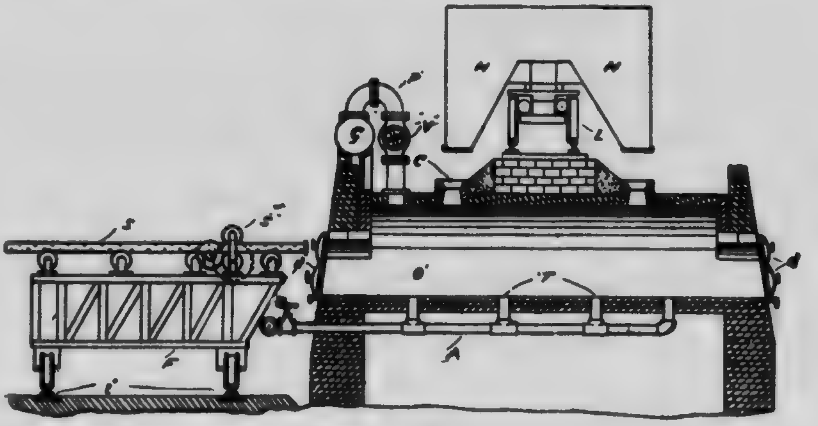


Figure 50

In order to illustrate the principle of the heating system of retort ovens, it is necessary to show the setting in sections bearing a relation to each other, and Fig. 51 is taken on lines 1 to 1''' of Fig. 52A, which shows the producer, air recuperator and combustion flues on one side of the setting. The part A Fig. 52, is a vertical cross-section of the same half of the oven setting on the line 2 to 2''' of Fig. 51, and B is a cross-section of the other half on line 3 to 3'''. The section A, Fig. 53, is taken on line 4 to 4''' of Fig. 51 and is on the same side of the oven setting as B, Fig. 52, but looking in the opposite direction, whilst B, Fig. 53, is on the same side as A, Fig. 52, looking in the opposite direction, and is taken on lines 5 to 5'''. The Fig. 54A is a horizontal cross-section on one side of the setting on line 6 and 6', Fig. 51, and B is a similar section on the other half of the setting taken on line 7 to 7'.

Referring to Figs 51 and 52, *O* is the coke oven, *P* is the gas producer, *G* is the gas recuperator, *A* is the air recuperator, and *f′* are combustion flues on one side of the setting, whilst *f″* are combustion flues on the opposite side of the setting.

A centrifugal fan *F* supplies the necessary air which passes along pipe *p* to inlet passage *p′* in the front wall of the recuperator *A*. From these passages it enters the flues p^3 and p^4, from which it is distributed to vertical flues *V*, located on each side of the setting. Dampers are provided at *d′*, which are closed when the operation is commenced by inserting a rod through the hand holes *h*.

A series of flues f^3 constitute the air recuperator and are adapted to conduct air to flues f^4 and f^5, where it divides into two currents in each of the flues. One of these pass to the producer through the duct *d″* in conjunction with hot gases passing through an injector *J*, whilst the main current passes to air nozzles *A″*, during which time the dampers on the air passages are closed. When the bed of fuel in the producer is well built up into an highly incandescent body, the charging chute *C* is closed, and the flame passes downwards and generates producer gas, which passes off to ports p^5 and through flues f^6 and f^7 to riser flue f^8. From the latter flue the gas enters the distributing flue f^9, from which it passes up vertical flues f^{10} of the producer gas recuperators *G*. The flues f^3 are supported by a plurality of traverse walls, built of specially shaped tiles *t* and *t′*, which rest upon key block *b*. The horizontal partitions *p* divide the spaces in front of and

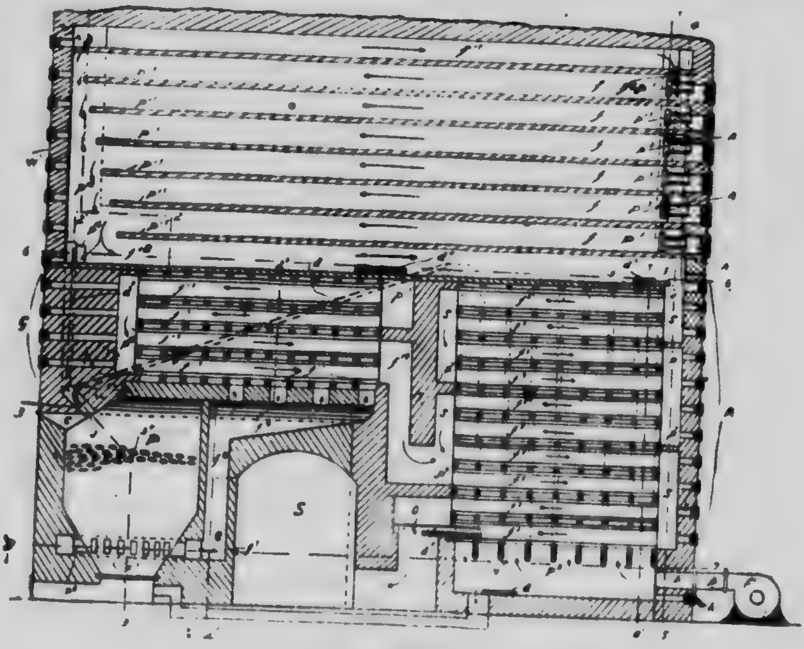


Figure 51

rear of the said flues in such a manner that they form groups, each of which comprises two separate flues, which are in communication through spaces S, so as to form a return bend flue.

A pair of open passages p^8 extend longitudinally to the recuperator, and serve to conduct the air from the series of flues f^3 to flues f^4 and f^5, and thence through port p^9 into the flue f^{13}, and through passages p^{10}.

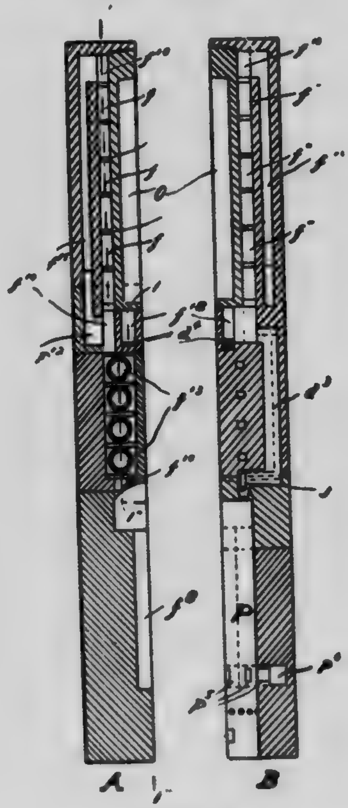


Figure 52

When the combustible gas has passed up flues f^{10} it flows along horizontal flues f^{13} into a collecting flue f^{14}, and through the port p^{12} to a riser flue f^{15}, and thence through flue f^{16} to downward flue f^{17}. The gas then passes through a series of ports p^{13} to combustion flues f' and enters the port p^5 on the other side of the oven setting to the combustion flues f''.

In the operation of this setting, the fuel in the producer is first built up to form a highly incandescent body which will generate producer gases according to the principles set forth in the previous chapter. When the gas is sufficiently rich to burn freely, the hand holes which give access to the combustion flues f' are opened, and the gases flowing from ports p^{13} are ignited by the insertion of a torch or red-hot bar. After the gas has been ignited at each port, the dampers and nozzles A'' on each port are opened, whereby the combustion which was initially by the air from the hand holes, is now supported by air from the nozzles. This produces a vigorous combustion within the flues, the products of which pass down through the passage p^{14} at the end of the combustian flue space. The length of the partitions p^{15} traverse along the front wall W' of the oven, and then into horizontal flue f^{18}. The latter flue distributes the gas into three streams, the first of which passes through port p^{16} and duct d^3 to the induction chamber of the injector J. This stream mixes with the air from the duct d'', and the commingled current passes through the injector into the gas producer and through the fuel bed. The second stream of combustible gases from flue f^{18} passes into passage p^{17}, and through flues f^{13} to connecting passage p^{18} of the producer gas recuperator G, and into the flue f^{19} and connecting passage of the air recuperator A. A damper d^4 on passage p^{17} serves to regulate the flow of combustible gases to the producer gas recuperator. The third stream of combustion gases pass through the length of flue f^{18}, and into passage S, from which it flows through the flues f^3, and finally mixes with the combustion gases from recuperator G

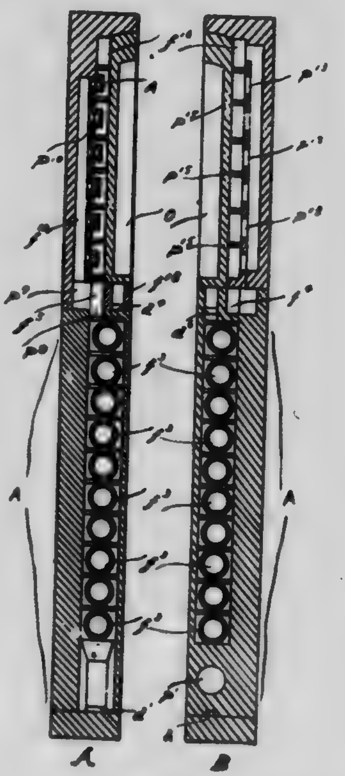


Figure 53

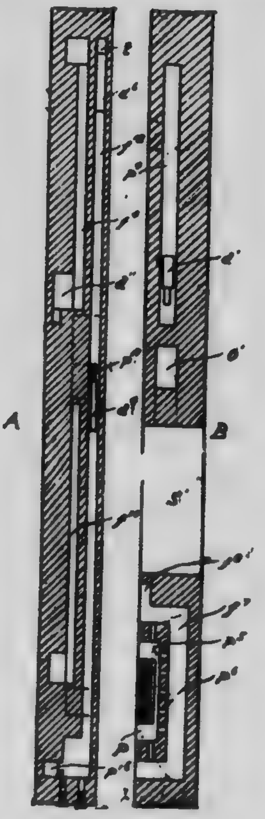


Figure 54

and passes through outlet O' to the smoke stack flue S'. A damper d^5 serves to regulate the flow of gases through O', and by careful adjustment of this in conjunction with dampers d^4 and d^6 any desired distribution of flue gases between the gas and air recuperators can be obtained.

After the producer fire has been clinkered and the bed of live fuel has been drawn down on to the grate bars by the removal of the clinker, the damper d is slightly opened, which allows a small portion of air entering the passage p^3 to pass through the duct to the ash pit of the producer. It then passes through the grate bars, and consumes any residual carbon that may have moved down unburnt on the grate by the shaking of the fire during the clinkering period. By this means the grate bars are protected against injurious high temperatures brought down upon them by the down-draft immediately after the clinking period when the bars are covered with a comparatively large amount of live fuel.

When normal operating conditions of the producer have been established, a blast of air from blower F is passed into recuperators A. A small amount of this air is passed to the ash pit and upward through the lower part of the fuel bed, whilst the greater portion passes to the recuperators. The latter portion is thus heated by the hot products of combustion passing through the flues f^3, after which it divides into two streams, one of which goes to the producer and the other goes to the combustion flues around the oven. The gases from the producer pass through recuperators G, where the temperature is raised by the hot products of combustion through flues f^{13}; and from the said recuperators the gas flows to ports p^{13} up each side of the setting and into the combustion flues, where it is burned by the superheated air from nozzles A''. The hot combustion gases on passing through the flues give up the greater portion of their heat to the oven, after which they split up into three streams, and pass to the producer, the producer gas recuperator, and air recuperator, as previously described.

COKE QUENCHING: When a charge of coal has been completely carbonized, it is common practice to employ some form of water spray for quenching the coke, which results in the vaporation of water to steam. This steam has been collected and used for various purposes, but in many cases it is objectionable, owing to the presence of a large amount of sulphur and ammonia compounds which are evaporated with it. Whilst these compounds are objectionable in certain cases, they are of value as by-products, and by passing the steam into the gas producer the nitrates and sulphates can be recovered.

It is obvious, however, in quenching the coke the steam is generated at intervals which bear no relation to the rate at which it may be fed to the producer, for which reason the steam has to be stored as hot water.

The principles of heat storage from steam is well known in various processes and is, briefly, that of leading the steam into water to which it gives up its heat, and renders the liquid capable of being evaporated at a comparatively smaller cost of fuel.

In this particular example of heat storage from the steam, the arrangement of plant is somewhat different, and is illustrated in Fig. 55, in which O is a series of ovens of the retort class, from which coke is discharged into a truck t, which is provided with perforated walls for expansion due to the hot coke. The loaded truck is run on to a platform *P* over a water tank *W*, through a door in the tower t'. The platform is adapted to be lowered into the tank to quench the coke, during which time the door of the tower is closed. The steam generated by the quenching rises in the tower and is brought into direct contact with hot water passing down a series of baffles. By this means the steam gives up its heat to the water by which it is condensed. A pump p' forces water from the storage tank t'', to which the water returns after passing through the tower, and a pump p'' also forces water from tank t'' to tower t^4, which has a series of baffles *b*.

A blower b' has its intake joined in the upper part of the tower t^4, and draws air through holes *h* at the bottom of the tower, so that the air is heated and becomes saturated with water vapor, which carries in suspension with it the vapors of ammonia and sulphur compounds. The mixture is then passed to the gas producer p^4 for the generation of gases for heating the ovens, after which the products of combustion are passed through scrubbing and washing apparatus for recovery of the desirable compounds.

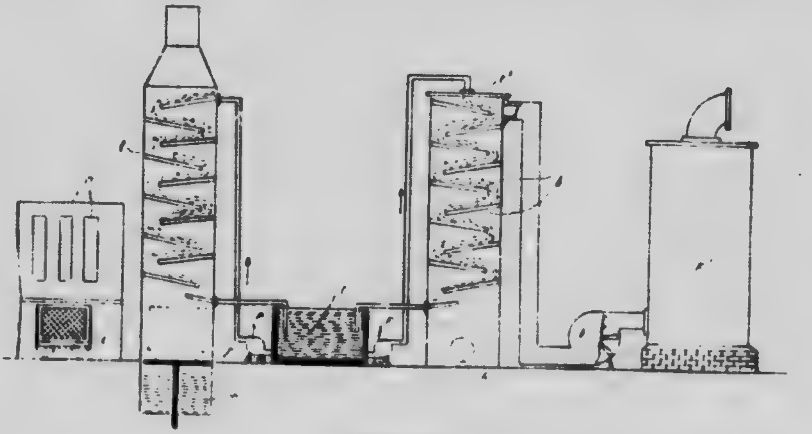


Figure 55

AUTOMATIC CONTROL OF COMBUSTION: In the utilization of coke in gas producers which serve to heat the ovens, some difficulties have arisen in the uniform distribution of heat, in that the fuel is apt to be completely burned in the lower part of the combustion chambers, with the subsequent evolution of heat therein, at the expense of heat around the top of the oven. This has the effect of completely carbonizing the coal in the oven at the bottom long before the top is carbonized, which results in a coke not homogeneous.

The concentration of heat near the lower part of the combustion chambers frequently becomes so great that it tends to destroy the by-products, and simultaneously results in the rapid deterioration of the chamber walls. These conditions have long been a source of objection to the use of fuels high in carbon, such as the coke produced in the ovens, and various apparatus have been designed to obviate the objections in an efficient and economical way.

In certain designs of ovens the gas generated therefrom is led into the combustion chambers surrounding the ovens, and are utilized for the subsequent heating of the oven from which it was originally distilled. This practice under average conditions is not economical, as the gases are usually more valuable for the manufacture of by-products, although it occasionally happens that the storage of these becomes too large for various reasons, and the use of such a fuel then becomes an economy.

The use of these gases, either isolated or in conjunction with gases from the producer, has resulted in many cases of uneven distribution of heat, and the localizing of extremes of intensities owing to the different composition of the gases from the ovens and those from the producer.

In the design of apparatus illustrated hereafter, the mechanism associated is adapted to be largely automatic in operation, and may be readily adjusted to control under varying conditions as desired.

The process will first be illustrated in its application to coking plants of the combination type, which are provided with means for pre-heating the fuel gas by passing through regenerators previous to combustion, or admitting direct to the combustion chambers without pre-heating.

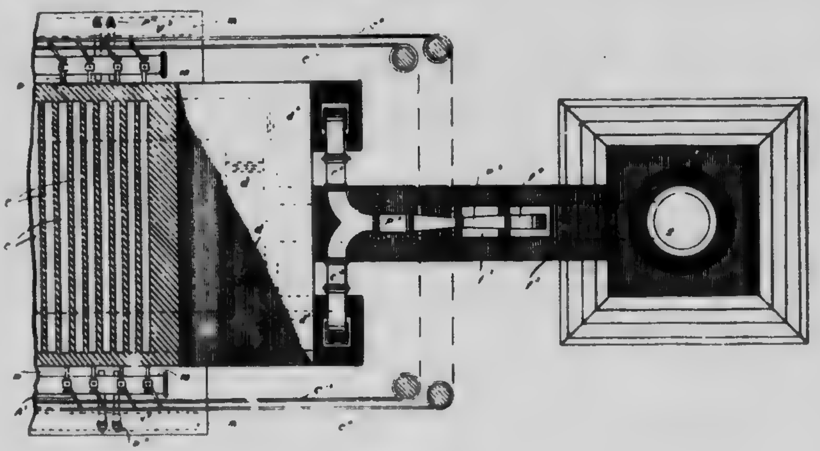


Figure 56

In Figs. 56 and 57 it is seen that a plurality of coking chambers C alternate with a series C' and combustion chambers C''. The chambers C and C'' are constructed by walls of highly refractory material and extend clear across the ovens as seen in Figs. 58 and 59, the former of which is taken on line 1........1 of Fig. 57. In each combustion chamber three inlets are provided, of which two of them i are adapted to admit either all air or air and fuel gas from regenerators as desired; whilst a third i' is adapted to admit fuel gas which has not passed through a regenerator from a main M, Fig. 60. These inlets all open vertically into the combustion chambers so that the air and gas moves in substantial parallelism. The regenerators R, of which there are two sets, extend throughout the whole length of the battery, as shown in Fig. 59. These are set under each transverse half, and are separated by a plurality of main dividing walls W and partition walls W'. The said partition walls serve to divide each space between the two main division walls, and with the interior of the combustion chambers through the apertures i. In this arrangement it is evident that the two regenerators provided on each side of the main wall, communicate with the combustion chambers immediately above the wall, so that if it is desired to pass the fuel gas through regenerators, it may be admitted to adjacent regenerators separated by the partition wall W' from main M', Fig. 59, that leads into alternate pairs of regenerators 2........2, Fig. 58; whilst air is admitted to the remaining regenerators 3........3, by which it is able to admit air and fuel gas into each combustion chamber as desired.

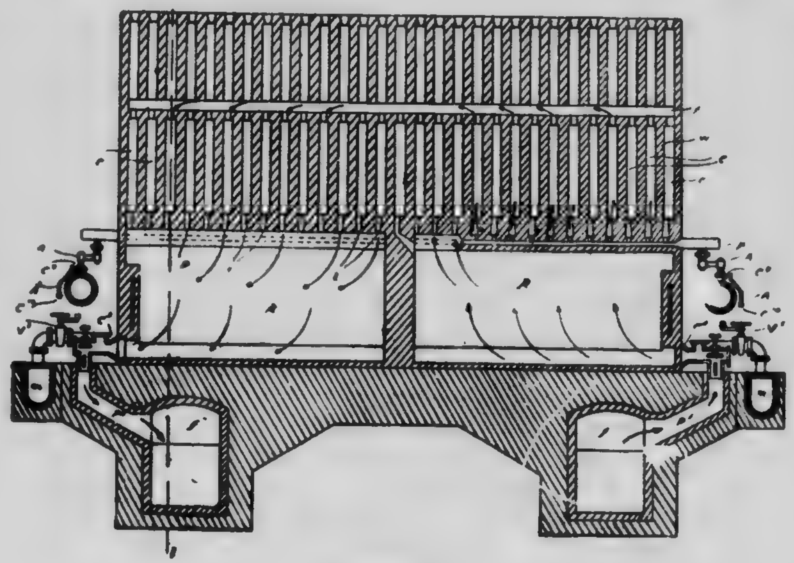


Figure 57

When the fuel gas is introduced into the combustion chambers without being pre-heated by regenerators, it is conducted through the main M, which is connected at intervals with a cross pipe p', extending between each set of combustion chambers, and from which suitable connections lead to inlets i'. The two sets of regenerators are operated alternately, one of which is adapted to heat the air, or air and fuel, while the other is receiving heat from the products of combustion in the chamber C''. Each series of combustion chambers open into flue f', Fig. 57, which extends the whole length of the setting over the wall W''' which separates each individual combustion chamber. The products of combustion from the chambers pass over and down the remaining chambers communicating with the regenerators and then into flue f'', which leads to stack S, Fig. 61. The regenerators R' also communicate with flue f'' through a connection C^3, Figs. 62 and 63, which comprises a valve chamber V leading one end p'' to a passage p^3 communicating at one end with the flue f'', and at the other end

p^4 with the entrance p^5 of regenerator R'. The passage p^3 is adapted to be closed by a mushroom valce V' co-acting with the seat S', and is operatively connected to mechanism which is adapted to open the passage p^3 leading to one flue f'', and simulatneously close the passage leading to the other flue f''. The air is admitted to each regenerator by way of pipe p^6 which may be closed by valve $V,''$ and is adapted to communicate with each connection C^4. The valves V'' and V' are connected together so that they both actuate simultaneously.

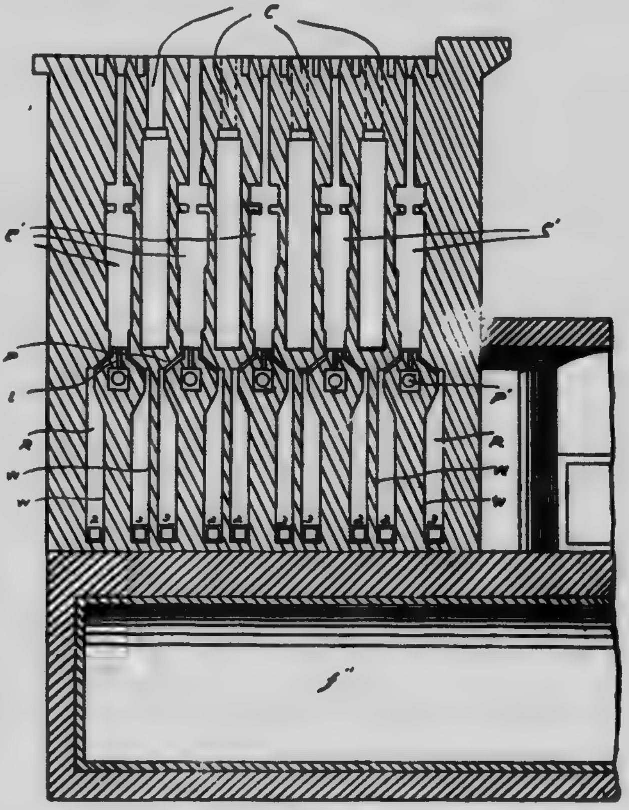


Figure 58

On each side of the battery a cable C^4 is provided, and is secured by stops S'' which are appropriately spaced to move past the connections C^3 when the cable is operated. The operating mechanism of one valve is a duplicate of the other, and the description, therefore, will be confined to one only. A pair of arms *d*, Figs. 64 and 65, extend upwardly from the top of each connection C^3, and carry in their upper ends a normally revoluble shaft S^3. At one end of the shaft there is fixed an arm *A*, which is bifurcated at its lower end *b*. The cable C^4 extends through the lower end of the arm, and is held in position by a pulley p^7 carried in the lower end of the arm. An arm A' is also fixed on the shaft S' and extends forwardly towards the mushroom valve V'. At the free end of the arm there is provided a chain C^5 which is adapted to lift the said valve when the shaft S^3 is moved from the position shown in Fig. 65 to that shown in Fig. 64, by the movement of the arm A. On the top of the connection C^3 a bell crank C^6 is pivoted at p^8, and has an arm extending over the valve V'', and is connected therewith by a pivot p^9. The rod R'' is also pivoted to the bell crank at C^7, and extends through a slot in the arm A^2, which is secured on the shaft S^3 and is parallel with arm A. On the other end of the rod R'' a stop S^4 is provided so that the swinging of the arm A will move the bell crank C^6 about its pivot and thereby actuate the valve V''. The stops on the cable C^4 are arranged so that they will first engage the arms to the left, Fig. 65, and move the arm A so that it opens the valve V' and closes the valve V'' when the cable is moved in one direction, and to engage the arm on the right when the cable is moved in the opposite direction, and thereby close valve V' and open valve V''.

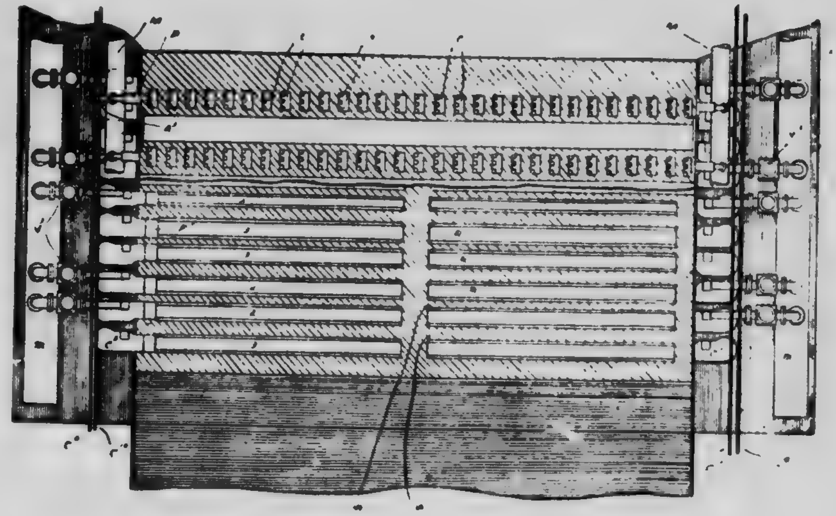


Figure 59

When a gas of low calorific value is being used, such as those from a producer, it is passed through alternate pairs of regenerators 2........2, Fig. 60, entering such through the connection C^3 and pipe p^{10}, Fig. 62. This pipe leads from a main m', and is provided with an opening in the air inlet p^6 of the connection C^3. A valve V^3 is located on each pipe p^{10}, and each valve has connecting arms A'' to the cable C^4, so that they operate simultaneously with the air valve V'' of the connection C^3, which are connected to adjacent regenerators 3...... 3. The pivot p^9 of the valves V'' of the regenerators 2......2, through which the gas is passed, are removed so that the valves remain closed and uninfluenced by the valve operating mechanism. When a gas, however, is not passed through the regenerators, the main m' is cut off, either by valves V^3, which may be dissociated from the operating mechanism and left closed, or by disconnecting the pipes p^{10} and closing their open ends by flanges. Under these conditions the gas is admitted to the combustion chambers from the main M, through connections C^8 which lead to the auxiliary main p', and the air is admitted to all regenerators 2........2 and 3........3 at the appropriate side of the plant; the valves V'' of the connections C^8 leading to the regenerators 2........2 being connected to the operating mechanism for this purpose. On the connection C^8 there is provided a cock C^9 which is connected to an operating arm A^3, Figs. 57, 64 and 65. All these arms are connected with a cable C^{10} on each side of the plant, so that the cocks C^9 are actuated together.

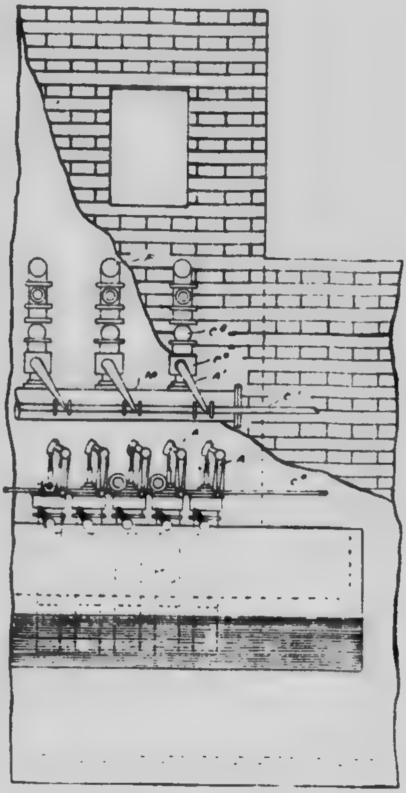


Figure 60

Under these conditions where the coking plant is being heated by producer gas alone, the combustion in the chambers is somewhat slow owing to the low calorific value of the gas. When the air and gas is drawn through the setting by the draft of the stack, the evolution of heat in the combustion chambers is evenly distributed on the walls of such owing to the comparatively slow rate of combustion, which enables the stack draft to substantially move the burning gases to the top of the combustion chambers before all the heat has been given up in the lower part of the chambers.

With the use of coke oven gas, which has a calorific value comparatively higher, it is more difficult to distribute the heat evenly owing to the specific gravity of the gases being much lower than that of the air for combustion and consequently the combustion is localized in the lower parts of the chambers, and therein produces extremes of intensity on one part to the defect of another.

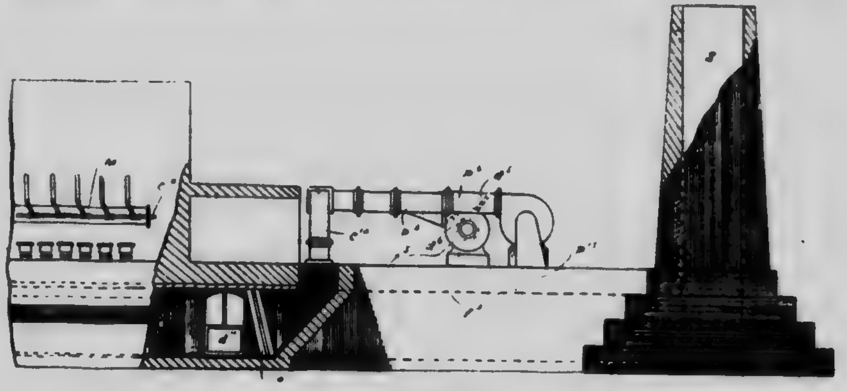


Figure 61

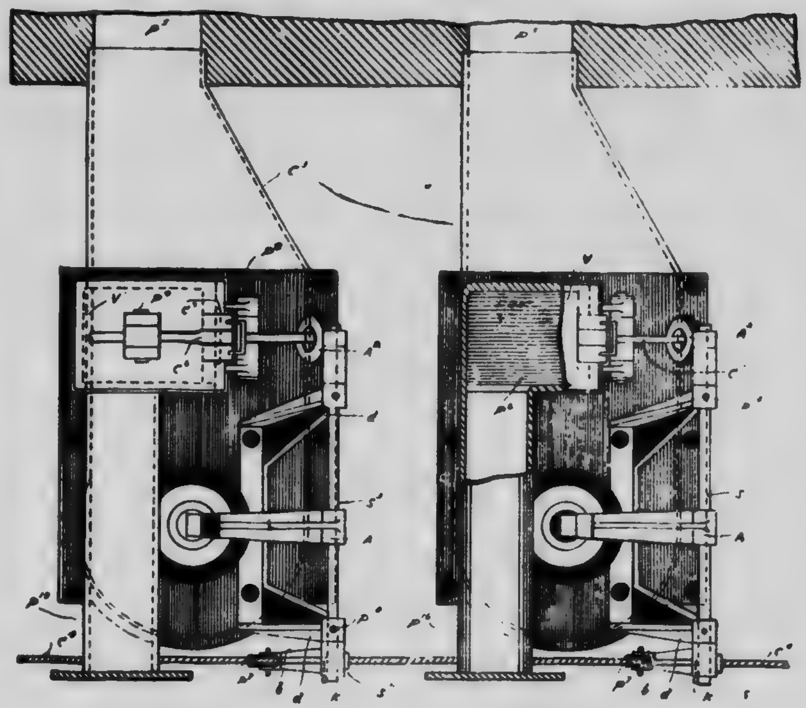


Figure 62

In order to remedy these conditions and preve[illegible]lizing of heat, it is found that by admitting a combustion supporter [illegible]e at high velocities, the rapidly combustible gases can be made to substantially reach the tops of the combustion chambers before they are completely burned, and thereby produce an elongated flame in each chamber.

The fluid used to support the combustion of gases under ordinary conditions is atmospheric air, but owing to the high velocities at which it is admitted in this case, the proportion of oxygen which is the combustion supporter, is found to be too large, and the excess produces complete combustion immediately it meets the rich gases. It is found, however, that by diluting the air with burnt gases, or gases which will not support combustion, the desired results are much improved. The burned gases are led from the flues and mixed with air previous to entering the regenerators, and on leaving the latter, the mixture is forced into combustion chambers at a desired pressure under which the combustion is caused to travel over the whole surface of the chambers.

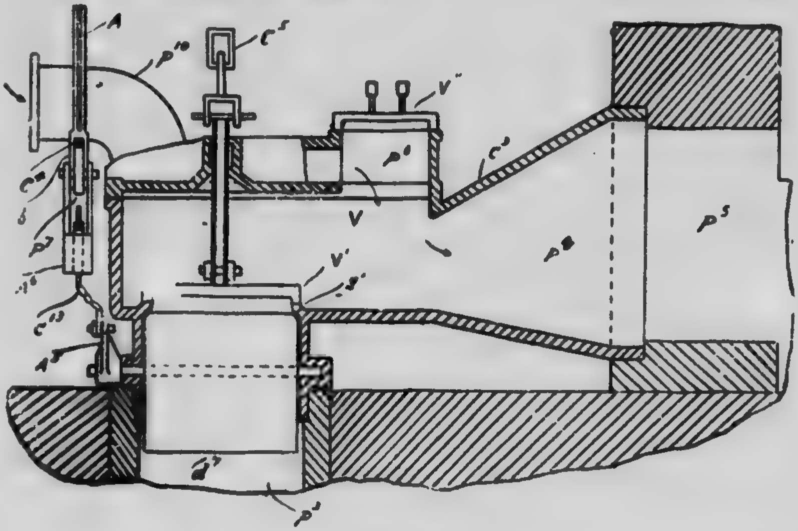


Figure 63

The mixture of air and flue gas leads into the regenerators through the valves V'' and is conveyed to the connection C^3 to the stack flue f'' communicating with regenerators pre-heating the air, as indicated by arrows to the right of Fig. 57. The two flues f'' are connected by a union from which a flue f^3 leads to stack flue S; dampers d' and d'' being provided to cut off the respective flues from the union. The air is delivered into flue f'' by a pipe p^{13} leading into each flue, and communicating thereto at C^{12}. A pair of dampers d^3 and d^4 are adapted to co-operate with the dampers d' and d'' to establish communication between one flue f'' and flue f^3. When the air is being delivered to regenerators through the flues f'', instead of valves V'', the said valves are kept in their closed position on both sides of the plant, and the mushroom valves V' are kept in their open position. This is effected by the adjustment of the valve operating mechanism, and pins p^{14} are inserted in aperatures extending through the bearings in the arms d, and through the shaft S^3, whilst the arms A are disconnected from the shaft by withdrawing the keys K. This permits the arms A to move freely under the action of the stops S'', without affecting the position of the valves or other mechanism associated therewith.

The flue gas when taken from passage f^3 is mixed with air in the pipe p^{13}, Fig. 61, and a pipe p^{15} connected with the flue f^3 is provided with a fan f^4 for the drawing of gas therefrom. The fan is connected by a pipe p^{16} with the pipe p^{13}, the latter of which receives air from a fan f^5. The two fans thus provided are adapted to draw flue gas and air respectively, and to permit the formation of a predetermined mixture of these fluids, the flue gas pipe is provided with a damper d^5 and the air pipe with a damper d^6. Under such provision it is obvious that the relative proportion of flue gas can be obtained by the adjustment of the two dampers, and the speed of rotation of the fans. A damper d^7 is also provided in each connection C^3 and is operatively connected to the cable C^4, so that their position is regulated in accordance with the regenerators being used for preheating the mixture. When air and gas are being conducted through the connection C^3, an unrestricted opening is effected through the connections, and when

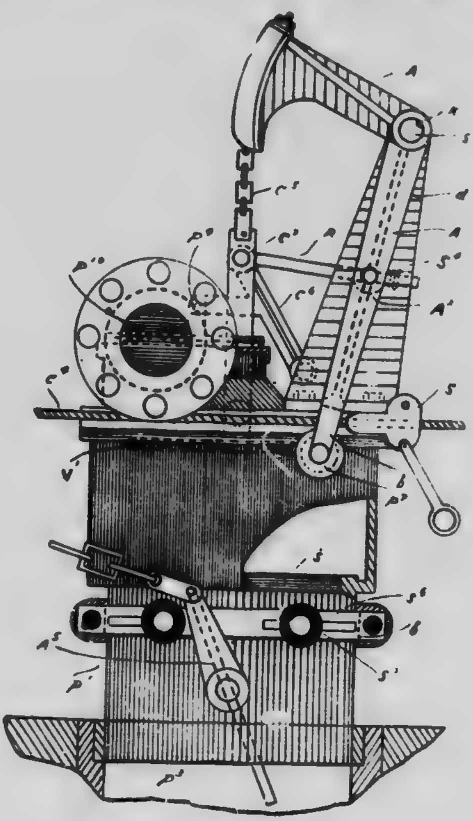


Figure 64

flue gas alone is being conducted to the stack flue, the damper is partially closed, so that the flue gas is not drawn through the regenerators being heated too rapidly. The movement of this damper is affected by the arm A^5 which is fixed on the pivotal axis of the damper. The end of the arm is loosely connected by a chain C^{10} with the end of a weighted arm A^6 pivotally carried on a stop S'', and the movement of the cable C^4 causes the dampers to swing from side to side as the direction of the flow of gas through the plant is reversed.

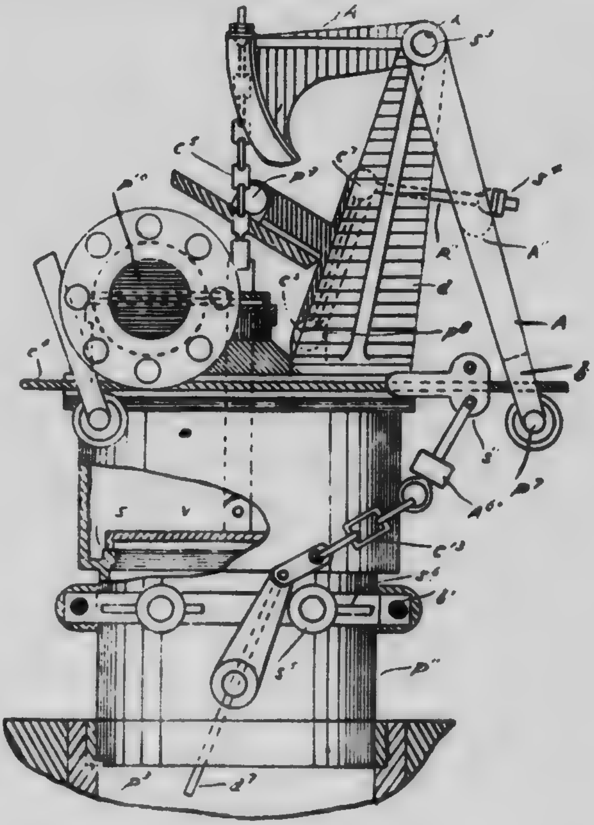


Figure 65

The movement of the dampers is limited by the stops S^5 protruding across the path of movement of the arm A^5. The stops are secured in slots S^6 provided in a bar b' which is made fast on each conn ction. The position of the stops are adjustable by moving them into a different slot and this permits adjustment of the extreme positions of the dampers under the action of the weghted arm A^6.

The apparatus will now be illustrated to the type of plant in which the gas is not pre-heated by the regenerators. In Figs. 66 to 69, the modifications are shown, and the figures represent parts similar to Figs. 58, 60, 61 and 59, respectively. The plant is similar in construction and valve mechanism, with the exception that no partitions are provided between the main walls W^3 of the sets of

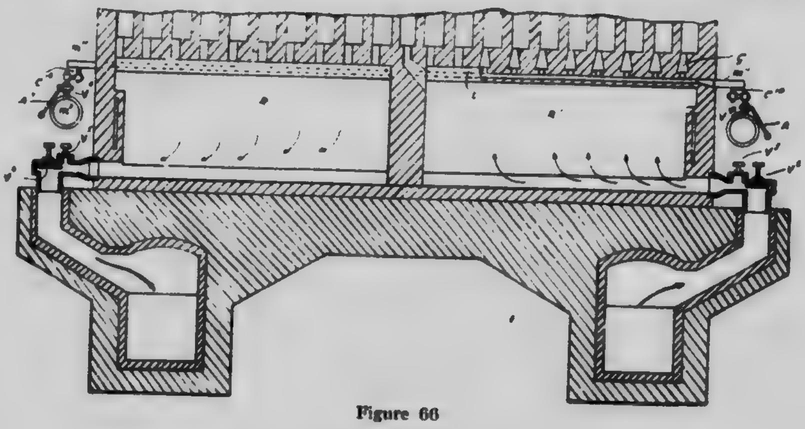


Figure 66

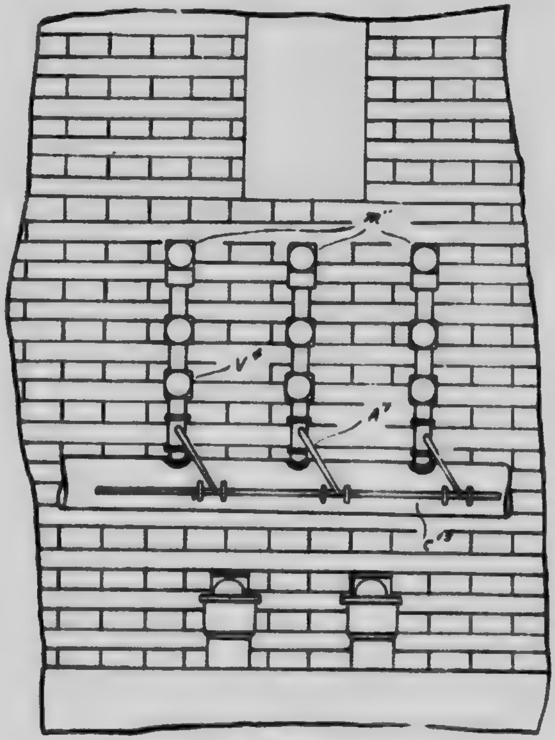


Figure 67

regenerators, and also two inlets only are provided in each combustion chamber. One of these i'' is for the admission of air from the single regenerator R'' between the walls W^3, and the other G is for fuel gas from branch main m''. Both of these inlets are vertically disposed adjacent to the combustion chambers, so that air or mixture of air and fuel gas enters the combustion chamber in substantial llelism. The fuel gas is delivered through the main m^3 communicating with main m'' through connection C^{14} provided with valves V^4 adapted to be operated by arms A^7 engaging at their ends in cable C^{15}. The air valves V^5 and mushroom valves V^6 are located in the same position as valves V'' and V' described in the previous apparatus, and are operated by similar mechanism.

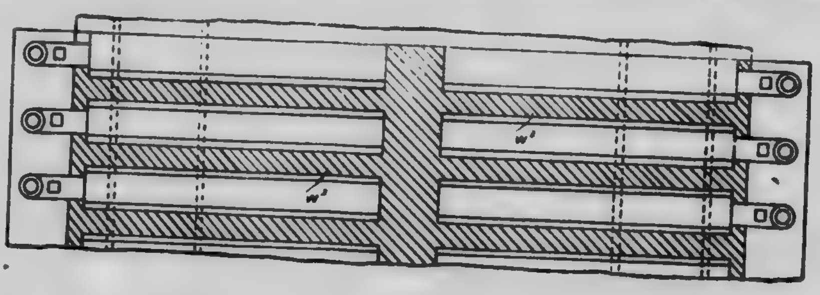


Figure 68

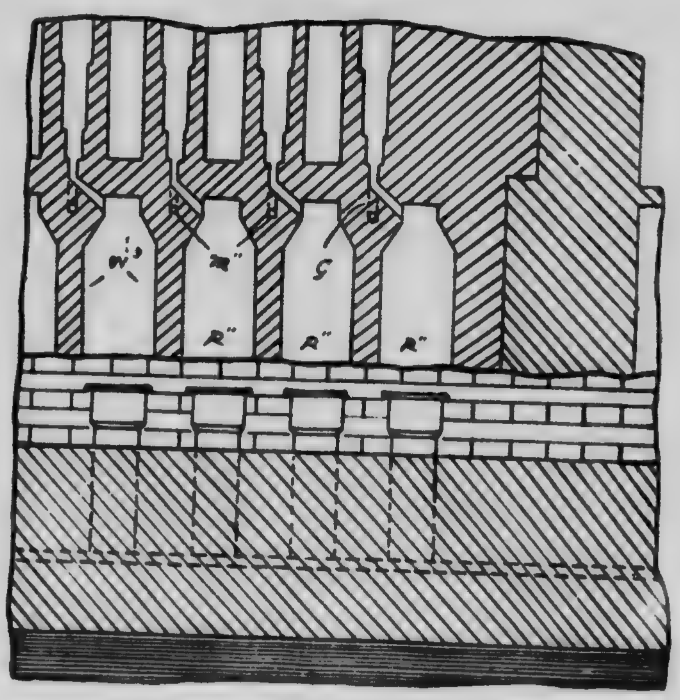


Figure 69

The two types are in other respects similar in construction, and from the foregoing description it is evident that by diluting the atmospheric air with gases which do not support combustion, the rich combustible gases are caused to burn at a slower rate, and the increased velocity at which the combustion supporter is admitted causes the burning gases to travel over the whole surface of the chambers and thereby distribute evenly and produce a better grade of coke.

In the mechanism associated with these plants it is obvious that the rate of combustion can be positively and accurately controlled by the adjustment of the dampers and speed of rotation of the fans, to meet the requirements of varying compositions of gas according to the relative percentages of producer and coke oven gas, and the maintenance of temperatures around the ovens which are found to be specially suitable to certain classes of coking coals.

COMPOSITION: A form of solid fuel that has been developed with a remarkable degree of success in many localities, is a composition of matter molded together to form a fuel of convenient and standard size. These substances, which are commercially known as *briquets*, have been made of various compositions of matter according to different localities, but, in general, it may be said that they are composed of some form of finely divided carboneous matter held together by a high compression or an adhesive substance to form a fuel of heterogeneous structure.

PEAT: The development of the peat-bogs into commercial fuel gives promise of a great future, and should be of special interest to Canada, when it is considered that some thirty million acres are known to be peat-bogs. The treatment of peat for the manufacture of fuel may differ according to commercial conditions, and it may be destructively distilled for the manufacture of coke and by-products, or disintegrated and compressed for the manufacture of briquets. The composition of peat is practically the same as coal, and differs only in that it has a lower density, contains a high percentage of moisture, and is less concentrated. The subject of re-modelling peat into commercial fuel has been discussed considerably in the last few years, and schemes have been approved and disapproved by various experts. That peat can be successfully converted into useful fuel is undoubted by the writer, but the prospect of commercial success lies more in the economy of preparation of the peat previous to carbonization or briquetting. The conversion of raw peat into producer gas is illustrated in Fig. 44, page 86, and such plant is admirably suitable for power purposes in the vicinity of production, but for general use the peat must necessarily be converted into a fuel of higher heat value per pound before it can be economically transported to industrial centres.

PREPARATION: The preliminary expenses in the preparation of peat lies in the excavation, cutting, and drying, and it is necessary to review the developments in these lines before considering the actual carbonization.

The greatest developments have been made in the North-West European countries, and the peat has been largely subjected to destructive distillation with the object of recovering nitrates for the manufacture of explosives. The nature of peat is not favorable for coking, and when the manufacture of fuel is the first importance, a briquetting process is the most satisfactory.

The process of excavation and cutting of peat as adopted in Europe, consists of a portable centrifugal pump dredger with a rotary cutter on the suction pipe to reduce the peat to a pulp, or other floating outfit of similar construction. The dredger, or primary cutter, consists of rectangular frames with sharp edges, the bottom of which is provided with large valves which open when the frames are pressed down, and closed by the weight of the peat when it is lifted. The frames are lifted with racks and pinions. The peat is then dumped at the suction pipe of the pump where it is reduced to a pulp by rotary cutters and the pulp, which consists of about 90 per cent. water, is conveyed through piping to a wooden trough leading to the drying plant, which may be of indefinite distance.

The greatest difficulties and expense in the preparation of peat has been in the elimination of the high percentage of moisture, and it has been treated by squeezing or crushing machinery; chambers in which dry air is forced through; and other drying apparatus designed to remove the moisture at the least cost.

It is to be noted that the mechanism for the primary treatment of peat should be easily transportable, as the location of the source of raw material is continually changing, and it is more economical to eliminate the water as near to the source as is practical, and avoid unnecessary weight in its transportation to the manufacturing plant. In order to meet these conditions, the simplicity of design is an important factor, and the supporting frame for the operating mechanism should be of bolted wood or steel so that it can be easily taken down and rebuilt when its movement in one piece is impractical; an incident which frequently takes place owing to the difficulty of travel in the bogs.

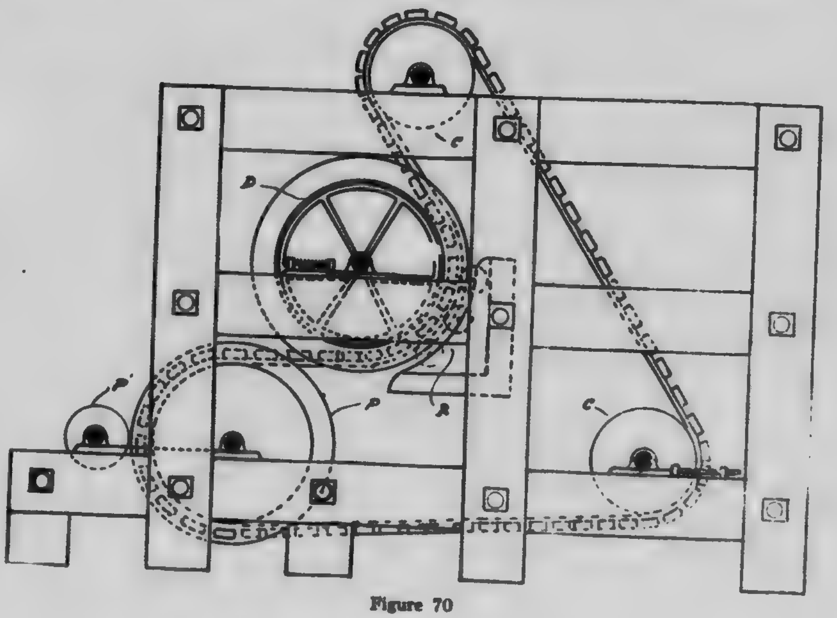


Figure 70

A simple and efficient design of squeezer, which is easy to construct, is illustrated in Fig. 70. This apparatus consists of a wooden frame upon which bearings are mounted, and carry a squeezing drum *D*, a driven pulley *p*, and a pair of counter pulleys *C* and *C'*. The whole is driven from a power shaft *p'*. The pulleys carry a driving band formed of a sprocket chain carrying wooden boards which are relative in shape to boards on the squeezing drum. The wet peat is fed on to the band in front of the squeezing drum and travels through the crushing boards to a point beyond the highest part of the drum, where it is removed by a scraper and delivered through a shute on to conveying or other transportable apparatus for shipment to the plant. At the point *R* a series of rollers located in an iron frame, are adapted to exert a pressure on the back of the conveying band and the squ[illegible] drum is mounted in adjustable bearings held by springs, so that they y[illegible]n the pressure becomes above the normal by the passage of an excess of material or solid obstacles, which are liable to be carried along with the peat.

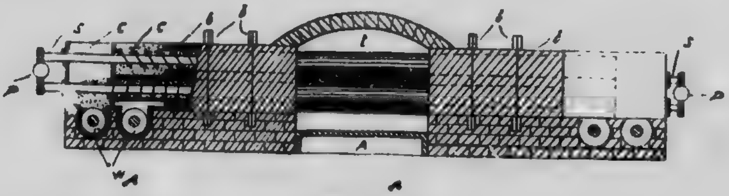


Figure 71

EKENBERG'S WET-CARBONIZING PROCESS: The wet carbonizing process has a particular advantage in that the volatile constitients of the peat are retained, which makes the final product more equal to coal. The principles of this process lies in subjecting the peat to a temperature of 180 to 230°F., or sufficient to evaporate the moisture, and it is carried out under a pressure of 200 to 300 pounds per square inch, which prevents the formation of steam. Under these conditions the slimy hydro-cellulose is destroyed, which has the effect of altering the properties of the peat, and disintegrating it so that the water can be easily pressed out. This process is suitable for peats of all ages of ripeness, and disintegrates the young and old peats alike.

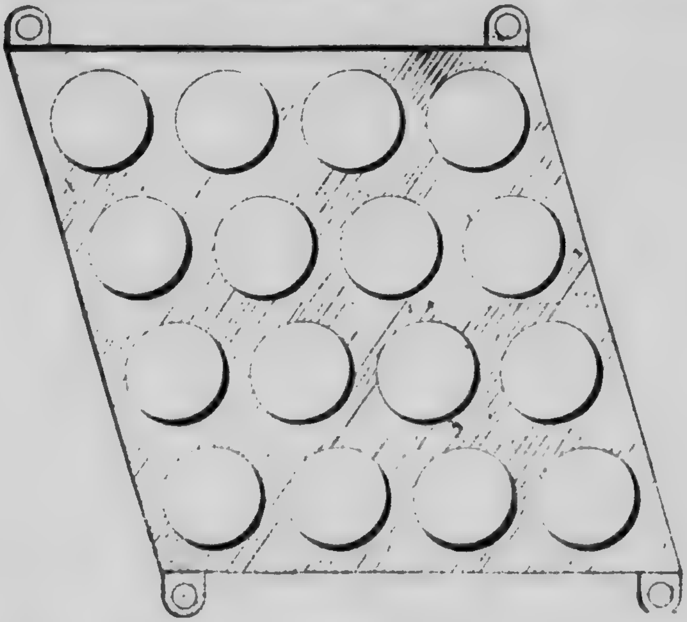


Figure 72

The general construction of the wet-carbonizing plant is simple, and the operation is continuous. The raw peat from the bog is first treated by any of the usual methods for reducing to a pulp and it is forced through the carbonizing plant by pumps specially designed to take care of the high pressures employed. The carbonizing plant consists of a plurality of tubes *t*, Fig. 71, which extend across the combustion chamber of a furnace A, and are connected at their ends with blocks *B*, shown more fully in Fig. 72 and 73. On each side of the furnace, about three of the said blocks are provided, and are connected together by bolts *b'*, Fig. 71. The first of these blocks constitute the side walls of the combustion chamber of the furnace and beyond the last block a chamber *C* is provided for the supply of material to the tier of conduits whilst a chamber *C'* is adapted to receive the material from the lower tier after it has been treated.

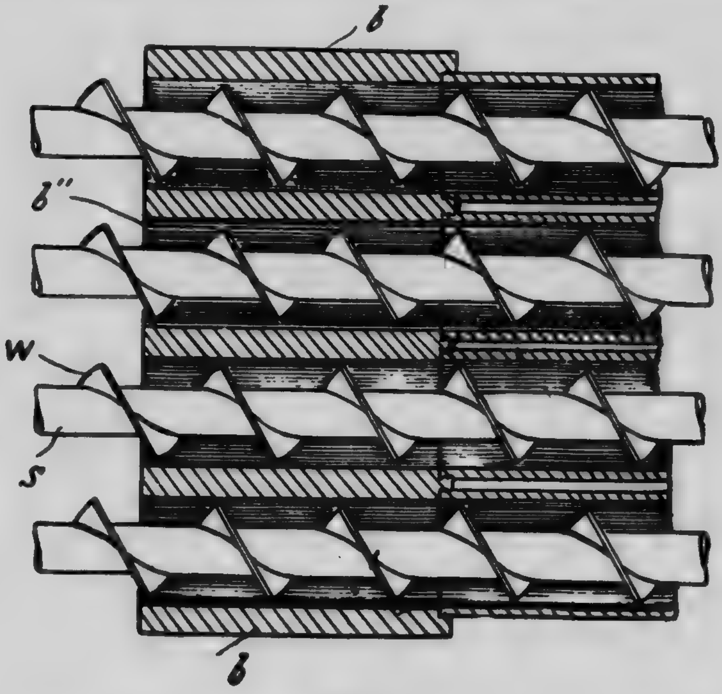


Figure 73

In each conduit there is a shaft *S*, on which is formed a worm conveyor *W*, driven from a source of power at *P*. The worm wheels of the conveyor gear with the upper and lower tiers of conveyors on opposite sides, respectively, as seen in Figs. 71 and 74, and consequently those located in the upper chamber are caused to rotate in one direction and carry the peat along the conduits towards the right of Fig. 71, whilst the lower conveyors cause it to return to chamber *C'* from which it is removed by worm *W'*.

The blocks *b* are made of cast iron, and the bores *b''*, Fig. 72, are disposed in them so that they form alined prolongations of the respective heating tubes *t*. In this arrangement of construction the middle portion of conduits only receive the heat direct from the furnace, whilst the end portions of the conduits are protected from the heat; consequently the middle portions are made of larger dimensions. The object is that as the vapor is generated from the peat as it passes over the furnace, it is retained in the tubes by the resistance offered by the wet material in the end portions. It is evident, then, that as practically no escape of steam vapor is allowed, the material is disintegrated and the slimy matter destroyed or changed without actual loss of moisture, which it is desirous to retain at this stage of the process.

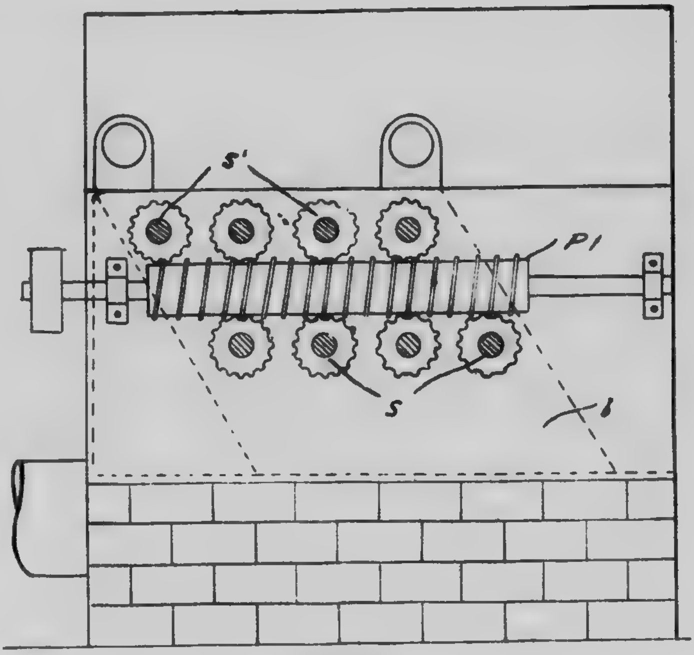


Figure 74

The primary objects of the treatment described is to effect disintegration without loss of moisture or other vapors, as it is claimed that the presence of such assists carbonization, in that it acts as a conductor for transmitting heat to all parts of the peat.

A development of the previous arrangement is that in which disintegration and carbonization is caused to take place at one step. In this arrangement, Fig. 75, the peat in its raw state is heated to a temperature of 300°F. to 500°F. for a period which may vary from 10 to 40 minutes, according to the nature of the peat; the older varieties invariably requiring longer periods at greater heats than the young peat.

According to this modification, a plurality of tubes *t* are placed within a firebrick setting *S*, having a furnace located at one end *F*. The tubes are closed at the furnace end and are open at the opposite end into a feeding chamber *C*. Adjacent to the feed chamber, there is located a chamber *C'*, into which a series of inner tubes t' extend from the tubes t. The wet peat is charged into a hopper, from which it is forced into the heating apparatus by means of a high pressure pump, and finally brought to chamber C at one end of the heating apparatus, and caused to enter the space between the outer and inner tubes t and t'. At the closed end of the outer tubes the material is caused to turn and move through the inner tubes in the opposite direction to its movement between the tubes. The material moving over the furnace is heated to a degree at which charring or carbonizarion takes place, and a portion of the heat imparted is transmitted to the material moving towards the furnace in the right half of the plant, which has the effect of causing the vesicles in the peat to liberate their water previous to its exposure to the heat of the furnace. The carbonized material is delivered to chamber C', from which it is led for further treatment.

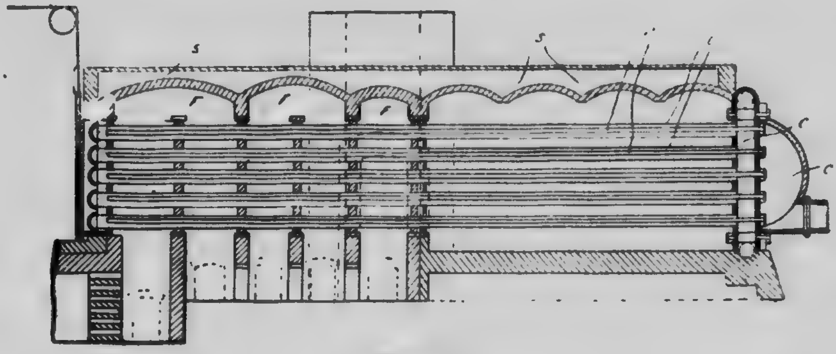


Figure 75

When the wet peat leaves the carbonizing plant, it is found that the percentage of moisture is comparatively large, and it is first air-dried, which has the effect of reducing the amount of moisture to 12 or 15 per cent. It is found, however, that this percentage is too high for successful briquetting, as the liability of steam generated from such has a deleterious effect upon the briquets, and causes them to crack. In order to obviate this disadvantage, the peat is passed through an open drier and heated to about 150°F. to reduce the moisture to about 3 per cent. after which it is transferred to a closed drier, and finally subjected in its highly heated condition into a high pressure open die briquetting press for shaping into the desired form.

LENNOX AUTOMATIC DRIER: The methods of peat treatment adopted by Lennox is covered by a wide range of patents, and whilst they are much the same as other systems, a particular feature of these is the efficiency of the drying plant. The Lennox dryer may be operated within a wide range of conditions, and is continuous and automatic in operation. The drying machine has a rotary action, and is adapted to spread the wet material over the shelves to a desired thickness, and on completing a turn on an upper shelf, automatically precipitates the peat through a hole on to a shelf below. This action mixes and turns the peat in its progress through the apparatus. The drying fluid is either hot air or waste gases from the manufacturing plant, and the temperature can be automatically controlled to suit the class of material and rapidity of operation.

LIGNITE: Another substance used for briquetting purposes is lignite, or brown coal, in view of the fact that the coal in its natural state is extremely brittle, and consequently is of little commercial value except to be used in the vicinity of production. The lignite usually contains from 30 to 50 per cent. of moisture, and the first step in its transformation into an artificial fuel is that of driving off the moisture in a suitable carbonizing chamber. The residue which constitutes the base of the artificial fuel or briquet is then finely pulverized and mixed with crushed coking coal in a proportion of 15 ot 1, respectively. The purpose of mixing a small percentage of ground coking coal with the carbonized lignite residue is to insure the coking of the mixture during its heating, and thereby produce a briquet that will not disintegrate. The mixture of coal and lignite is then combined with a small percentage of pitch of pre-determined consistency. The amount of pitch used is from 1 to 5 per cent., and it is introduced along with the mixture into an agitator which is heated to the melting point of the pitch, by gases which were driven off from the lignite in its carbonization. At this stage about one or two per cent. of flour or finely ground grain is introduced into the mixture, and, after continued agitation the mixture is conveyed while still hot, to some form of briquetting machine which molds the fuel into the desired shape and size. When the briquets are discharged from the machine and cooled they form a fuel which may be transported with comparatively small breakage.

FINE COAL: Another substance that has been successfully used in the manufacture of briquetts is fine black coal, which is of little commercial value in its natural state. The proceeding in this case is to first pulverize the coal and then mix it with an adhesive material which is wholly or partially soluble in water in proportions of 2 to 5 per cent. of its bulk. The adhesive or binding material may be flour, ground grain, starch or molasses, or other similar substaces which, when diluted with water to a certain degree, enable particles of coal to be moistened when the binder and fuel are mixed together.

According to this process the mixture is passed through a suitable briquetting machine, and the so far manufactured fuel is then passed through a chamber heated to 212°F. to expel the moisture. The fuel is then mechanically dipped into a receptacle containing fluid tar, after which it is exposed to a temperature of from 400° to 500°F. to volatilize the tar, and leave an impervious coating on the molded fuel sufficient to prevent its disintegration and protect it from moisture.

Immediately after the final heating has been completed the coating is chilled by mechanically conveying the fuel through a current of cold air, which solidifies the coating and makes it capable of being handled and stored without breakage or adhesion to each other.

COKE DUST: The use of coke dust as a base in fuel briquet manufacture has been adopted in suitable localities, and in one part the binder employed is an extract of cactus in liquid form. This extract is obtained by draining or tapping live cactus plants, or by reducing the plants to a pulp and treating the pulp with boiling water or steam. The solution produced is thoroughly mixed with coke dust and subjected to the pressure of a suitable molding machine according to the size and shape of the briquet desired. The medullary matter of the cactus is combustible and adhesive in its natural state, but when subjected to moisture and pressure its adhesion is increased; and under the conditions referred to it uniformly permeates the entire mass of coke dust with which it is mixed, and imparts thereto a glutinous coating of combustible matter.

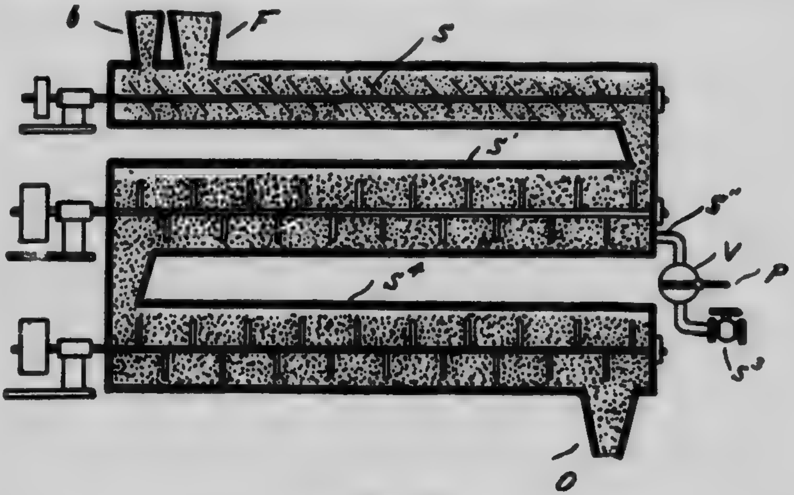


Figure 76

The process of manufacture in this case is much the same as in other processes with regards to mechanically mixing and drying, and the use of cactus plants as a binder is more economical in the vicinity of its production, and thereby enables the final product to be manufactured at a lower rate than when flour or other marketable binders are used.

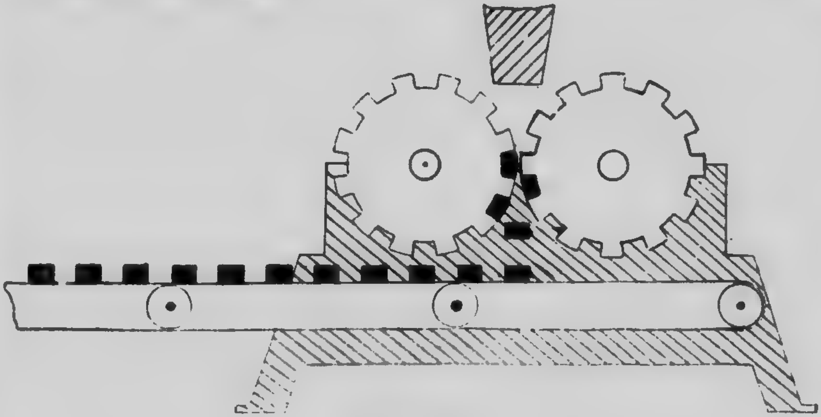


Figure 77

PITCH DUST: The use of pitch as a binder has been widely employed, and in its common application it may be said to possess a certain advantage, in that when it becomes warm, it adheres to members or other mechanical parts associated with briquet manufacture. This results in the necessity of frequent cleaning of the mechanism, and the occasional production of briquets that have not a homogeneous structure.

In one process which proposes to obviate this disdavantage, the pitch is transformed into a fine powder by melting it and spraying it through suitable atomizers, and then immediately lowering the temperature so that it solidifies into fine dust. The pitch dust is directed on to the fuel to be briquetted in a mixing drum, by which it is possible to obtain a mixture which is extremely homegenous.

Under these conditions, where the pitch is blown directly into the mixing drum closed to the atmosphere, it eliminates the escape of dust, and the consequent injury to the health of workmen associated with the operation of the plant, and also insures a more thorough uniting of the binder and fuel, and consequently a better class of briquet.

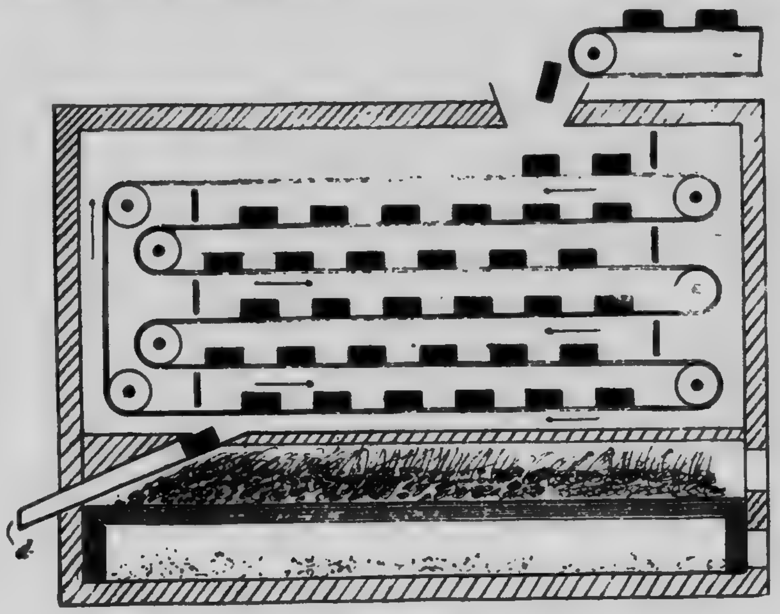


Figure 78

BRIQUET MOLDING APPARATUS: The plant used for the manufacture of briquets usually consists of a mixing device, a molding machine and a drying chamber, through which the material passes respectively. The combination of apparatus may differ somewhat in design, but the principle is much the same in all, and a simple arrangement which serves to illustrate the operation is shown in Figs. 76 and 78.

Referring to Fig. 76, the finely ground fuel and binder is introduced into the apparatus through *F* and *b*, respectively, and conveyed through the top section *S* into middle section *S'* by the rotation of a shaft which carries a series of arms or stirrers. The mixture on passing through section S' is caused to commingle with steam from pipe S'' which carries in suspension with it an oleageneous substance, such as water gas tar. The steam and tar are mixed together in valve V, into which the tar is conducted by pipe p, and passed through a wire gauze terminal so that the tar is broken up into small globules, whilst the steam enters at S^3 and carries the globules of tar along with it.

On passing through section S' the mixture descends into the lower section S^4, and finally is conducted to the outlet O where it descends into a molding machine or press similar to the one shown in Fig. 77, by which it is shaped into the desired form and size.

When the briquets pass through the press they are delivered on to a conveyor which carries them to drying chamber, Fig. 78, through which they are conducted on a conveyor in an atmosphere of hot air and delivered therefrom at d.

COAL BRIQUETS: In the manufacture of briquets from coal, the apparatus used may be of varied construction, but the principle is similar and may be illustrated by the system hereafter described. The proceeding in this case may be briefly stated as follows:

(1) The coal is crushed in water to a pulp.

(2) The pulp is fed directly to a mold and compressed therein.

(3) The partially formed briquets are passed through a tunnel, wherein the temperature is gradually increased from below the boiling point of water at the entrance to just below the decomposing point of coal at the exit.

(4) The dried briquets are subjected to a relatively high compression to complete the consolidation of the fuel.

In the first step of this process, the small coal is ground in hot water by passing through a mill in the proportion of about 2 to 1, respectively. The aqueous pulp is then introduced into a mold without being left to settle, where it is compressed to eliminate the proportion of water, and consolidate the substance into briquet form. The compression is generally from 7,000 to 10,000 pounds per square inch, and is applied to the pulp by plungers as hereafter described.

Referring to Fig. 79, the mold consists of an outer casing C, which is lined on the interior with a series of vertical bars b, which are secured by bolts passing through flanges f and the flanges f' of the casing. The flanges f' have grooves sunk in them to receive the flanges f, so that the end surface of the mold is unbroken, and the adjacent side faces f'' and f^3 of the bars converge and meet the edges located at the interior of the mold. This forms a practically continuous surface on the interior of the mold, and at the back of each of these surfaces there is a series of vertical throughways of V-section, which are adapted to lead away the water forced out of the pulp and between the bars.

Within the mold there are two oppositely acting plungers p and p', which are fluted on their vertical plates at v and v', respectively, and on their end faces at e' and e''. The plungers are also provided on their end faces with a series of bars b' and b'', respectively, which runs transversely on the flutes e' and e'' in the end faces of the flutes; these bars being secured to the plungers by screws S and S'. The adjacent side faces of the bars b' and b'' converge in a similar manner to the faces f'' and f^3 of the bar b, and meet at the edges of e^3 and e^4, which are situated at the interior of the mold. By this means the water pressed out of the pulp may readily drain off from the faces of the plungers through the flutes and throughways provided.

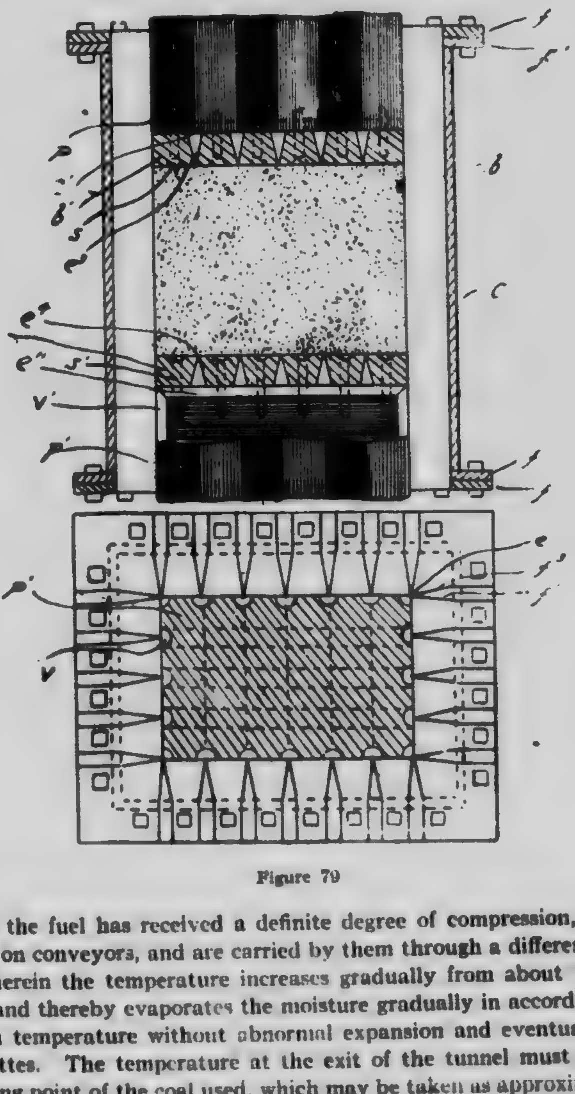


Figure 79

When the fuel has received a definite degree of compression, the briquets are placed on conveyors, and are carried by them through a differentially heated tunnel, wherein the temperature increases gradually from about 160°F. at the entrance, and thereby evaporates the moisture gradually in accordance with the increase in temperature without abnormal expansion and eventual cracking of the briquettes. The temperature at the exit of the tunnel must be below the decomposing point of the coal used, which may be taken as approximately 575°F. for bituminous coals to 900°F. for anthracite. It may be pointed out however, that the heating of the briquets after the moisture has been evaporated is only to be carried so far to cause an incipient softening of the fuel, and the decomposing point must not be reached. Under average conditions, where semi-bituminous coals are used, the final temperature is about 500°F.

On leaving the tunnel the dried and incipiently softened coal, is placed in a second mold and subjected to a hot and relatively high compression to complete the consolidation. These molds are usually heated by steam, and are similar in construction to those illustrated, but are not provided with the moisture draining system. They are also fractionally larger than those used for the first compression, owing to the expansion of the briquets during the heating. The pressure is applied simultaneously on both sides of the mold, and may be from 5 to 15 tons per square inch, according to the class of coal. It should be noted that in this process the briquets are made without the addition of binding agents, and the final product is purely a structure of coal.

COMBUSTION AND FLAME: The combustion of solid or liquid fuels results in all cases in their conversion to gas before the heat units are evolved In order to thoroughly understand the combustion of gases, it is necessary that we study its relation to flame under different conditions.

The luminosity of a flame obtained from gases distributed for commercial purposes is due to the presence of carbon particles which are heated to incandescence by the high temperature of the flame. The nature of those gases is practically a mixture of hydrocarbons; and when ignited in contact with an adequate supply of air, the hydrogen of the gaseous compounds is caused to ignite the first by reason of its lower density and consequent greater affinity for the oxygen of the air than the carbon. This results in the liberation of free carbon in the interior of the flame, and under the intense heat the carbon becomes incandescent and thereby produces light. The burning particles of carbon are eventually distributed throughout the flame and consumed as carbon dioxide.

The character of a flame obtained from a given volume of gas is greatly influenced according to the following conditions:

(1) When gas is burned in an insufficient supply of air, the flame produced bears a yellowish tint.

(2) When burned in an adequate supply of air, the flame becomes white.

(3) When combustion takes place in an excess of air, the flame becomes shorter.

(4) When the air is greatly in excess of that required for complete combustion, the flame assumes a bluish tint.

In the first instance the carbon particles are not heated to a sufficiently high temperature, which produces incomplete combustion of the carbon, and causes a large proportion to be passed off in the form of smoke. In the second instance where complete combustion is effected, the carbon is raised to its highest state of incandescence, and the white flame produced gives the greatest proportion of light. In the third instance, where the supply of air is in excess, the flame is diluted, and therefore becomes shorter but cleaner. In the last instance, where the air is greatly in excess, the luminosity is almost destroyed, and the flame is caused to assume a bluish tint. This flame does not evolve more heat than when the supply of air is just sufficiently in proportion, but it is of value in that it enables burning gases to be applied to solid bodies without the depositing of soot which is characteristic to the luminous flame. The non-luminous flame caused by the excess of air is known as the Bunsen flame after the inventor. The depositing of soot is due to incomplete combustion of some particles of carbon, and by such the conducting power of the body on which the deposit is made is reduced in efficiency; and to prevent such deposits on vessels which are being heated they must be placed at a distance from the luminous flame, so that it is diluted by air currents. In the bunsen flame an air inlet is constructed in the gas tube some 4 or 5 inches from the top, and at the same point the gas inlet is restricted to cause it to increase its velocity and thus draw in the maximum amount of air. The air and gas on passing up the tube are well mixed, which insures complete combustion at the burner. The blue flame emitted can, therefore, be applied direct to a solid body without the depositing of soot, consistent with the greatest evolution of heat. This condition is desirable for efficient application of gas for direct heating purposes.

HEATING CONDITIONS: The transmission of heat from one body to another or from one point to another, within the same body takes place in one of three ways:—By Conduction; By Convection; By Radiation.

When the progress of heat from a higher temperature to one of lower temperature occurs without any motion of the particles in the body, the progress of heat is by *conduction*. For instance, if a bar of metal is heated at one end, the other end will soon become hot by conduction from the heated end.

When heat travels through a body by the motion of the heated particles, the transferring of the heat is by *convection*. For instance, when a vessel of liquid is heated the particles in contact with the bottom are heated, and as they rise to the top, heat is imparted to the colder portion of liquid.

When heat is transferred from one body to another across an intervening space without affecting the temperature of the space, the transferring is by *radiation*. For instance, a body placed in front of a fire will be heated, whilst the air through which the heat passes will not be affected except those parts in contact with the heated body. The greatest example of radiation is the heating of the earth by the sun, in which the intervening space is approximately 92,000,000 miles.

The practical application of these principles are employed in heating appliances for the maximum evolution of heat or concentration on to a given point as desired.

In the cooking of food, or in the generation of steam, the heat is received direct on the cooking utensil or boiler and transmitted through it by *conduction* to the liquid in the interior, where it is transmitted to the food by the circulation of the heated fluid, or by *convection*.

In the warming of rooms or public buildings the heat may be transferred as follows:

(1) By means of fires—radiation.

(2) By circulating hot air—convection.

(3) By transmitting hot water or steam along pipes—convection; and causing the heated pipes to transfer heat into the room—radiation.

The most economical method of heat distribution is by the circulation of heated air, but this method has disadvantages in that the air is deteriorated for breathing purposes, and is, therefore, not healthy. The desirable conditions for heating of individuals is to allow the body to be comfortably warm, and simultaneously allow respiration to occur under healthy conditions—by cold air. It is evident, then, that the most desirable is by *radiation*, whilst the most economical is by *convection*, and to obtain efficiency with economy the two conditions are frequently combined as in the third instance, where the heat is transferred along pipes by convection and into the room therefrom by radiation.

The method of heating to be employed is a subject of varying conditions, and whilst one method is specially suitable for one purpose, it may not be suitable for another. In small rooms or offices, where the occupant remains in one position for a considerable time, a source of radiant heat is the most desirable. In large apartment houses, hotels, or workrooms, the systems are conveniently combined by warming the whole building to a moderate temperature by the circulating of hot air or steam through pipes. In public buildings which are not occupied by any one individual for a considerable length of time, the use of hot-air stoves is satisfactory and economical. In theatres or churches, in which heat is required for a given time only, the best method is by the circulation of hot air for some time previous to its occupation by the masses of people, after which the heat may be reduced or frequently cut off entirely.

REFLECTION AND DIFFUSION: In certain professions or arts it is frequently desirable to reflect or radiate heat on to a given object for drying purposes, where a direct application of heat is impossible. The diffusion of heat in this manner is influenced by the employment of artificial means, such as shades or reflectors around gas flames. The use of these obstruct the heat in varying proportions according to the material of which they are composed, and enable it to be diverted from one path and concentrated on another. The angle of distribution has considerable influence in obtaining the maximum amount of heat from a given value, and should not be less than 60 degrees. The material of which the reflectors are composed affect the concentration on to a given point considerably, and those made of copper, enamel, porcelain, or opal are the most efficient. These principles are employed for heating small rooms, and embodied in the so-called *Reflector Heaters* used for this purpose.

In previous remarks it has been shown that the complete combustion of gases evolve an equal number of heat units regardless as to whether the flame was luminous or non-luminous, but the non-luminous flame is most suitable for the direct application of heat, owing to it being cleaner. In the reflector heater for small rooms, the luminous flame has the advantages in that it radiates more heat, owing to the fact that it contains solid particles of carbon heated to incandescence; consequently this flame is desirable for use in the reflector or radiating stove.

A modification of the reflector heater, in which the non-luminous flame is employed, is that class known as the *incandescent*, in which the flame is directed on to a number of skeletons made from a material which is raised to incandescnece from which the heat is finally radiated into the room. The material used for skeletons is generally fireclay, and they are made in various designs. The principle, however, is practically the same, in that gas jets burning in an excess of air are caused to impinge on the material and raise it to incandescence. The incandescent fireclay is caused to radiate the heat outward by a suitable wall behind it, and the whole setting is usually located in a frame of artistic design.

RADIATORS: The radiation of heat through a piping system, as used for stores, large apartment houses or workrooms, is accomplished by passing a hot fluid through the system in the form of gas or liquid. The heating may be by radiation in three ways:—By the gas radiator; By the steam radiator; By the gas-steam radiator.

The former of these consists of a number of cast iron tubes arranged in an artistic design, and into which a burner of the luminous type is fitted at the bottom. The tubes are open at the bottom and are provided with holes at the top to allow the burnt gases to escape. The object of this arrangement is to obtain a large surface of temperature at the minimum cost of fuel, and is, therefore, more suitable for use in public places or large rooms than the reflector or incandescent heater where the greatest proportion of heat is evolved in the vicinity of the stove.

The steam radiator, as controlled from a centralized coal or coke furnace, consists essentially of a series of piping connecting to a steam boiler. The steam is circulated through the piping, and radiating its heat therefrom, is condensed to water, which returns to the boiler to be re-vaporized. This system is suitable for very large buildings where it is practical to employ labor to take charge of the furnace and boiler.

The gas-steam radiator is similar in construction to the gas radiator, but is unlike the former in that it is not open to the atmosphere. In this system water is placed in the radiator and heat applied thereto by an atmospheric burner. This results in the generation of steam which circulates through the tubing and radiates heat therefrom, and is subsequently condensed back to water; which is re-converted to steam at the burners.

When the temperature of the room rises the condensation in the radiators is not so great, which causes an excess of steam to be generated. This is caused to exert a back pressure on a diaphragm connected with the gas valve to reduce the supply of gas accordingly. This system has all the advantages of steam heating systems which are controlled from a centralized plant, and have a further advantage in that the temperature of the room automatically controls the gas consumption and prevents an excessive pressure of steam in the piping system. The last named advantage is very important, as it prevents unequal expansion of the piping and is consequently safer. It also prevents the oxidation of hot pipe and disagreeable odors associated with it. The gas radiator is very suitable for hotels, apartment houses and workrooms.

WATER HEATING: The gas-water-heater is an applicance by which a supply of hot water can be conveniently obtained at a minimum cost. These heaters may be divided into two general classes; the *automatic* and the *storage*; each of which will be discussed in order. In the automatic heater the supply of hot water can be obtained practically instantaneous, and the principles are that of providing a large heating surface over which the water has to pass in the vicinity of a powerful battery of burners. The heating surface may be of varied form, such as a coil of copper tubing, or a series of horizontal tubes projecting across the heater so that the water passes to and fro in its downward path.

By the use of these applicances the temperature of the outlet water can be controlled to any desired degree by adjusting the rate of flow; it being obvious that an increase in the supply will lower the temperature for a given volume of gas, whilst a decrease will raise the temperature. An efficient applicance will absorb from 90 to 95 per cent. of the total heat of combustion, from which the amount of water capable of being heated from a given volume of gas can be calculated.

It may be stated that the heating value of gas is rated by the British Thermal Unit (commonly abbreviated B.Th.U.) which is "*The amount of heat required to raise one pound of water one degree fahrenheit.*'" The value of gases vary somewhat in different cities and an average might be taken as 580 B.Th.U. per cubic foot. Assuming that it is required to raise 10 Imperial Gallons of water (100 pounds) from 50°F. to 100°F. the amount of heat units absorbed from the gas will be:

$$(100-50) \times 100 = 5{,}000 \text{ B.Th.U.}$$

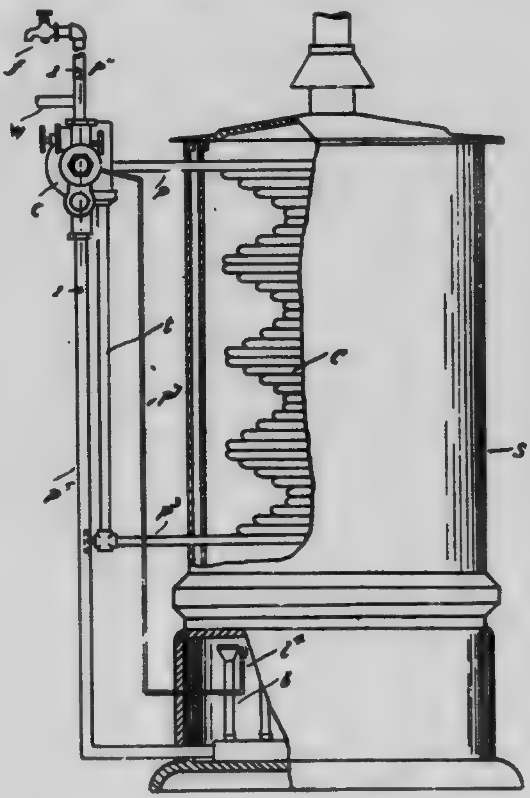


Figure 80

If the gas has a value of 580 B.Th.U. per cubic foot, and the efficiency of the applicance is in accordance with the average, or 92.5 per cent., the gas consumed will be:

$$\frac{5{,}000}{580 \times .925} = 9.32 \text{ cubic feet.}$$

AUTOMATIC-WATER-HEATER: In the best classes of automatic-water-heater, the valve mechanism is adapted to maintain a comparatively

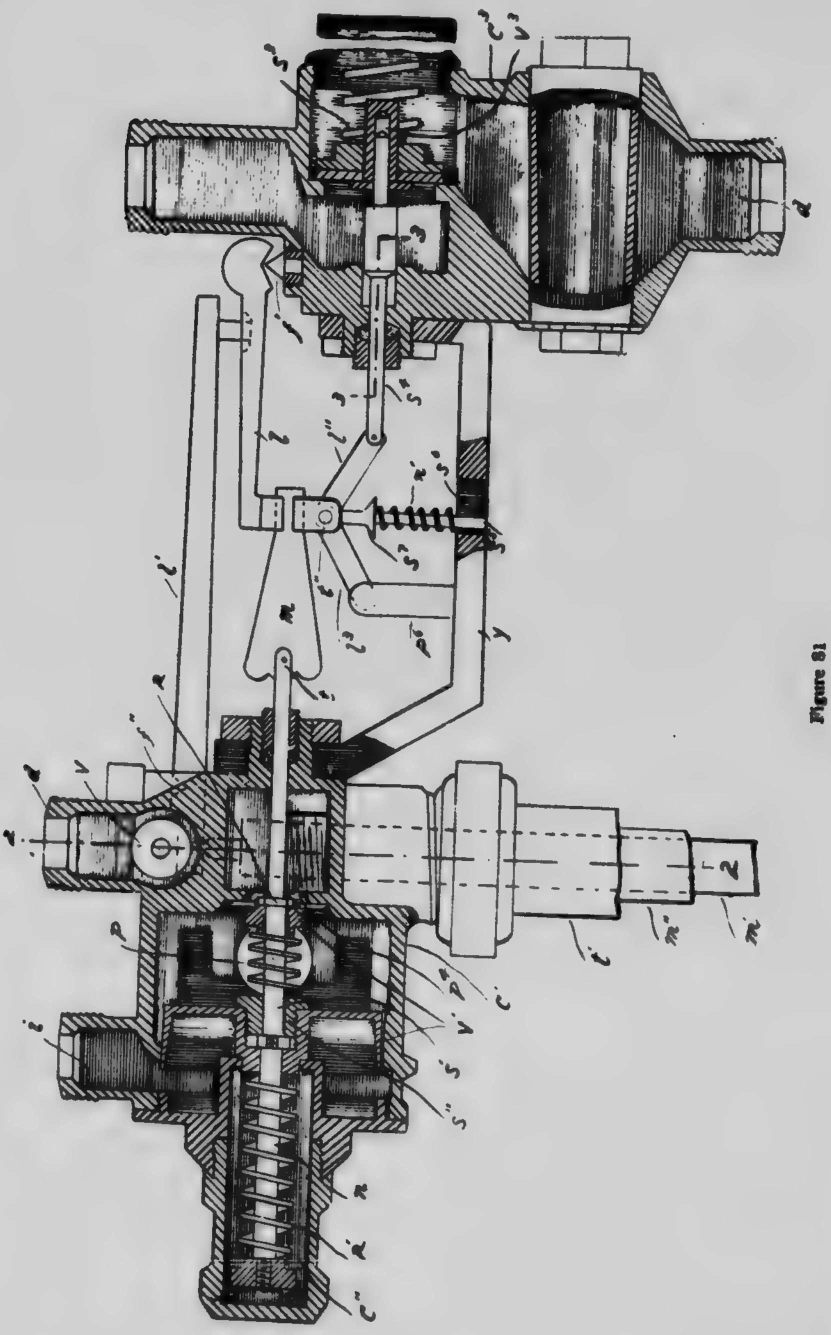


Figure 81

even temperature regardless of the volume of water drawn on it. One of the most efficient of these heaters is illustrated in Figs. 80 to 83,inclusive, in which S, Fig. 80, is the outer shell or casing, in which a plurality of copper coils are located in vertical series. The casing of the heater is double-walled to prevent loss of heat by radiation. The burners are located beneath the coils in the base of the heater and are adapted to ignite by means of a small jet or pilot light. The supply of water is connected to the heater through valve casing C', which is provided with an inlet i, Fig. 81, connecting to the water supply W, Fig. 80. The Fig. 81 is enlarged to show the detailed construction of the mechanism, and is taken on section line 1........1, Fig. 80.

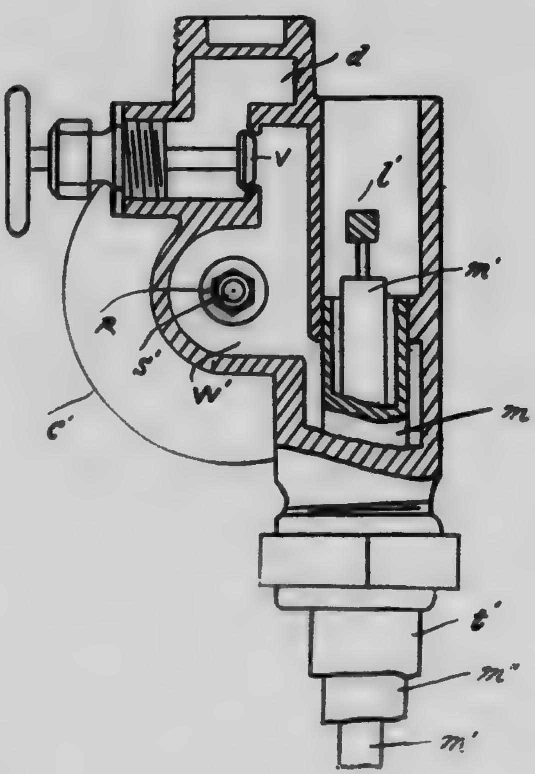


Figure 82

The casing C' is adapted to discharge the water through port p, Fig. 81, to the inlet pipe p' of the upper end of the coil C. A hot water inlet W', Fig. 82, and hot water discharge d are also connected with the casing. This figure is taken on line 2..... 2, Fig. 81. The hot water discharge is controlled by valve V and is connected to delivery pipe p'' leading to the house piping system to be used as desired, as by faucet f.

The hot water inlet *W′* is connected to the discharge pipe p^3 from the heater, and to cold water discharge through a circulating port p^4. The water inlet valve *V′* is of the piston type, and is adapted to be automatically opened by the pressure of the inlet water, when pressure is released in the heater by drawing of water therefrom. On the valve stem *S′* a circulating valve *V″* is loosely mounted and is held against the rest *R* by means of a coiled spring *S″*. The spring is arranged about the stem as illustrated, and the upper end bears against the valve whilst its lower end engages in the valve *V″*. The rest *R* is made adjustable to enable the valve *V″* to be adjusted to seat previous to the opening of the inlet valve *V′*.

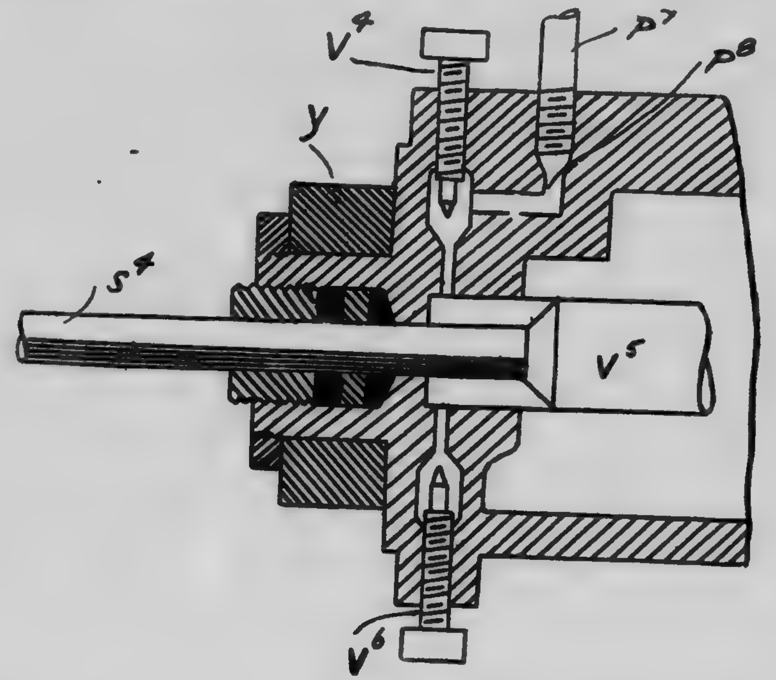


Figure 83

On the section *n* of the valve stem, a return spring *R′* is arranged, and is adapted to resist the opening of the valve *V′*, and close it when pressure is released on the valve seat. The spring is located in chamber *C″* and is in the form of a cylindrical cap-like extension of the valve casing, the upper end of which is adapted to be removed for adjustment or renewal of the said spring without disturbing the main cap of the valve.

The gas valve casing C^3 is provided with a gas inlet V^3 and a discharge *d′*, which is connected through pipe p^5 to the burners of the heater. The gas valve is held against its seat by means of a coiled spring S^3, and is connected through stem S^4 to operating mechanism, as hereafter described. A movable member *m* is tapered and pivotally mounted on the stem of the water-actuating valve *V′* through pivot *t*.

The lever L is adapted to engage the member m, and is mounted on a fulcrum f' on the gas valve casing C^3. The lever L is engaged by a lever L' which is fulcrumed at f'' to be engaged to a thermostat member m', which is connected to the tubular member m'' located in tube t' connected with the hot water outlet of the heater.

The movement of the member m is imparted to the gas valve stem S^4 through links L^2 and L^3, of which the former is pivoted to the stem, whilst the latter is pivoted to a post p^6 of the yoke Y, by which the valve casings C' and C^3 are connected. The said links are provided with a support for member m and are partially connected thereto by means of a pivot t''. The stem S^5 extends downwardly through a slot S^6 in the yoke Y for guidance, and is normally held by means of a coiled spring n', the upper end of which engages a shoulder S^7, whilst the lower end rests upon the yoke.

The pilot light L^4, which ignites the burners in the heater, is connected by pipe p^7 to a pasage p^8 of the valve casing C^3, as shown in enlarged view, Fig. 83; the view being taken on 3........3, Fig. 81. The normal flame of the pilot is controlled by valve V^6, and a valve V^4 is adapted to regulate the flow of gas for the flashing flame as caused by the movement of valve V^5. The valve stem S^4 is provided with a slip connection, so that the opening of the main gas valve is momentarily retarded to insure the opening of the pilot valve slightly in advance of the main gas supply and thereby enables the flashing flame to be established before a full supply of gas is presented at the burners.

In the connections herewith illustrated, it is evident that the opening of the gas valve is in accordance with the amount of water drawn from the heater, and also in accordance with the temperature of the hot water by the expansion of the thermostat in relation to it. This enables the temperature of the water to remain substantially constant, as an increase causes the thermostat to expand and reduce the supply of gas, whilst a decrease in temperature causes it to contract and increase the flow of gas; and also an increase in the demand for water releases the pressure within the heater and consequently allows the gas valve to open greater in accordance with it.

STORAGE-WATER-HEATER SYSTEM: The heating of water by the storage system is employed as a means by which a large volume of water can be heated with a comparatively small rate of gas consumption. The water heater is not designed to carry the large bulk of water it is intended to heat; and the greater bulk is stored in a cylindrical tank which is connected to the heater by a flow and return pipe. In the heating of water according to this system, the hot water in the heater is forced up the flow pipe into the tank by the cooler water from the return pipe which enters at the bottom, and so replaces the hot water by reason of its higher density. The cooler water is gradually raised in temperature and is eventually forced from the heater and replaced by more water from the storage tank. It is evident, then, that the tank stores the hot water and the pipe distributing system is therefore connected with it. As the hot water is drawn from the tank it is automatically replaced with cold water by a float valve. The cold water inlet is located in or near the return pipe to the heater so that it does not lower the temperature of the hot water in the top of the tank.

The storage system differs somewhat according to the purpose for which it is used, and in small installations the tank is frequently fixed above or near the heater, and is connected thereto by short flow and return pipes. In large installations it is frequently necessary to run a second flow and return pipe to the top of the building from the storage tank, and draw water through these pipes. This arrangement has the advantage of supplying water more quickly.

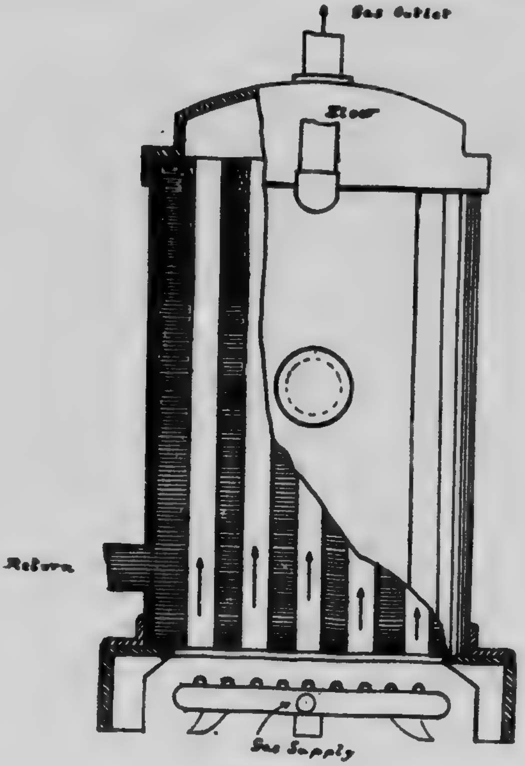


Figure 84

This method of water heating is widely used for various purposes, owing to the fact that the combustion of gas may take place in a suitable location and allow the heat from such to be transferred to a position in which combustion would be undesirable; for instance, in the heating of churches, schools, or other public rooms. It may be said that the storage or circulating heater differs from the automatic heater in that it has a smaller heating surface and smaller gas consumption in comparison with its size, and consequently the rise in temperature is comparatively slower. Under ordinary conditions the temperature can be raised about 30°F. at each circulation, so that the same water needs to circulate about 5 times in order to raise a volume of water from 60°F., to the boiling point. The circulation of hot gases within the heater takes place in various ways according to different designs, a common one of which is shown in Fig. 84.

This heater consists of a wrought iron cylinder supported on a cast iron frame, and having a cast iron cover fitted thereto. A series of vertical tubes are arranged within the cylinder and carry the burning gases to the flues as indicated by the arrows. The tubes are encircled by the water to be heated, which enters at the bottom through the return pipe, and flows from the top as it becomes hotter and lighter. The efficiency of a circulating system depends greatly on the length of the piping system and the consequent loss by condensation. When the piping system is of considerable length, it is advisablle to cover such with non-conducting material where the radiation if heat is not needed. When the water is used in public lavatories or for other domestic purposes, it occasionally becomes necessary to clean out the heater of deposits which occur from the circulation, and for this purpose hand holes are provided with removable doors.

HOT-AIR GENERATOR: In many industries, such as laundry work, printing, or other paper and tape processes, it is necessary to use a drying room in which a hot-air or other drying system isemployed. In the hot-air system the most efficient and practical way is by the circulation of a fluid from a suitable heater or generator which is capable of raising the temperature to a definite degree. Of these, the gas-fired heater is the most practical means and combines efficieency with cleanliness, the latter of which is a very important factor in such cases. This class of heater is made in various sizes, and is constructed of heavy steel shells, into which a series of steel tubes are fastened to conduct the products of combustion from the gas burners through the generator. The body of the heater is provided with an air inlet at the top, and outlet at the bottom; and the air is caused to circulate around the tubes on passing downwards whilst the burning gases are passed upwards through the tubes.

In general, the sizes of generator given below are suitable for ordinary classes of work, but heaters of other dimensions are made for particular cases:

(1) Diameter, 18 inches, Height 61 inches.
Gas Consumption, 90 cu. ft. per hr.
Air Capacity, 13,500 cu. ft. per hr.

(2) Diamter 26 inches, Height 76 inches.
Gas Consumption, 180 cu. ft. per hr.
Air Capacity, 27,000 cu. ft. per hr.

Under the above conditions the temperature of the hot air will be approximately 300°F., when the gas used is of standard heating value; and if such needs to be raised the capacity must be reduced accordingly; whilst a lowering of temperature would necessitate an increase in the supply of cold air, or decrease in the supply of gas.

ATMOSPHERIC RADIATOR: The atmospheric radiation system is a form of heating which is suitable for drying purposes where the work is of a sensitive nature. The heater is adapted to be placed inside the room through an opening in the wall, and air passed through it so that heat is absorbed from the walls of the conbustion chamber and transferred to the walls of the heater for the radiation of heat into the room. The products of combustion are passed from the heater to the outside of the room by a flue connection, and the atmosphere in the room is heated entirely by radiation, and is, therefore, free from gases which would affect the work. The h[illegible] is designed to have a large radiation surface in a limited space, so that considerable of the heat from the combustion of the gases is localized in the room and enables a drying temperature to be reached.

This system is specially suitable where it is necessary to keep the combustion gases out of the drying room, as such have a tendency to tarnish certain classes of work. These radiators are made in sizes from 3 to 10 feet long, with a gas consumption of from 40 cubic feet to 80 cubic feet per hour; and one cubic foot of gas has a heating value equivalent to three cubic feet of room space up to 200°F, with the atmosphere at normal temeperature and gas at standard value.

STEAM GENERATION: The use of steam for heating is desirable in many industries owing to the fact that its application is slow, constant, and uniform; and in such cases it is usually more economical and convenient to effect its generation by gas-heating than by the use of solid or liquid fuels. The advantages of gas-heating in these cases may briefly be stated as follows:

(1) It requires less attention and is automatic in control.

(2) It avoids insurance laws associated with the storage of liquid fuels.

(3) It is cleaner, safer and reduces ground space.

(4) It eliminates fuel storage and can be applied at any hour of the day or night.

(5) It possesses greater efficiency by enabling perfect combustion to take place with the concentration of heat on to a desired point.

(6) It can be applied without the provision of a flue, and the steam generator can,therefore, be located in the most convenient position.

(7) It eliminates the necessity of an attendant.

(8) It requires no investment of capital in fuel.

(9) It prevents loss of time in starting and can be shut down more readily.

(10) It is easily maintained and insures a constant steam pressure at all times.

The various industries in which gas-heating is applicable for steam generation are too numerous to refer to in a work of this kind, and only the most common will be quoted.

Arranged in alphabetical order these are:

Armature Repairing.
Artificial Flower Making.
Bleaching Laces, etc.
Blue Print Drying.
Button Manufacture.
Candy Boiling.
Chemical Laboratory.
Cloth Cleaning.
Dress Pleating.
Distilling Solutions.
Dye Manufacture.
Hat Manufacture.
Jewelry Cleaning.
Jewelry Plating.
Laundry Operating.
Rubber Melting.
Steam Baking.
Sterilizing Milk, etc.
Tobacco Moistening.
Umbrella Manufacture.

HEAT TRANSFER: The transferring of heat from the burning fuel to the water in the steam generator or boiler is accomplished by conduction and convection, which occur in their respective order. The burning fuel is caused to give up heat to the shell of the boiler, from which it is transferred through the plate to the interior by conduction, and given up to the particles of water in contact with the plate which transfers heat to the cooler particles by convection. The rapidity in which heat is absorbed by convection depends on the effectiveness of the water circulation of the boiler, and the extent of the conductivity of the heating surfaces.

In Fig. 85 the effect of the circulation and transfer of heat is shown in a plain horizontal boiler. This type of boiler is usually heated by a furnace located at the front end, and the heated currents of water rise from the hottest parts of the shell directly over the furnace and carry bubbles of steam with it to the surface. As the heated water ascends, the cooler parts from the back end take its place, and the circulation is thus continued in the direction of the arrows.

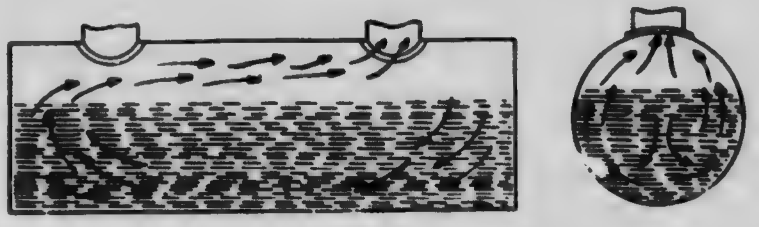


Figure 85

In the illustration it is seen that there are two currents, one carrying the cold water from the rear to the front, and the other carrying down the centre and up the outside of the shell. This circulation is in a direction opposite to the furnace gases. It is evident then that if the circulation of the furnace gases are caused to follow a particular path, the water also takes one path, and the circulation is more rapid and uninterrupted by opposing currents. If the water is heated in a U-tube, as seen in Fig. 86, a uniform circulation is set up and proceeds without interruption; and consequently steam is generated without the vigorous boiling associated with large masses of water, as in the cylindrical boiler. On this principle the water-tube boiler is founded, and is specially suitable for steam generation in small units where a constant pressure is desired.

Under ordinary conditions of steam production, the heat-giving substances are carbon and hydrogen, which, when combined with the necessary amount of oxygen at a suitable temperature, are caused to form compounds with their evolution of their heat. This combination will not take place at ordinary temperatures, and the fuel must first be raised to the kindling or ignition point before the elements will attract oxygen and combine therewith. When combustion is once commenced, the temperature of the fuel is kept above the ignition point and combustion will continue while ever the supply of fuel and oxygen is present.

Under this principle the use of solid fuels for steam raising originated, but owing to the fact that perfect combustion cannot be caused to take place in practice, the use of gaseous fuels promise to be more economical when applied by scientific methods.

In the combustion of coal the combination of hydrogen and carbon with oxygen produces gas which passes up the flues and chimney. The composition of coal is practically a mixture of carbon and hydrogen of varying densities, and consequently it is impossible to obtain perfect combustion, as one class of hydrocarbon requires more oxygen than another. When the temperature of the coal approaches the ignition point, the lightest gases are driven off first, and finally the fixed carbon of the fuel passes off in combination with oxygen.

The oxygen which supports the combustion constitutes 23 parts (by weight) of the atmospheric air; the remainder of which is nitrogen, which will neither burn nor support combustion.

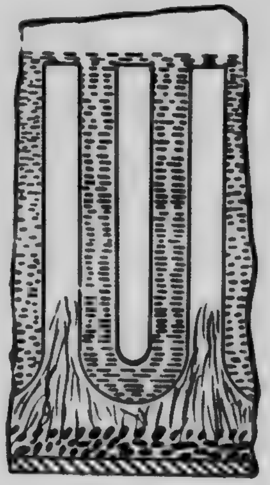


Figure 86

The amount of oxygen required for the complete combustion of carbon is, theoretically, 2 to 1 by volume, respectively, and as the atomic weights of oxygen and carbon are 16 and 12, respectively, the proportion by weight is 32 to 12, or 2.67 pounds of oxygen per pound of carbon. Assuming that the atmosphere is 23 parts oxygen and 77 nitrogen, the weight of nitrogen, mechanically mixed with 2.67 pounds of oxygen, is 8.93 pounds, or that it requires 11.60 pounds of air to completely burn one pound of carbon.

The oxygen required for the combustion of hydrogen is 1 to 2 by volume respectively. The atomic weight of hydrogen is 1, so that the elements combine in the proportion of 16 to 2, respectively; or 8 pounds of oxygen per pound of hydrogen. The weight of nitrogen present in this case is 26.8, so that one pound of hydrogen requires 34.8 pounds of air for complete combustion.

The volume of gas produced by the complete combustion of one pound of carbon under the conditions referred to is 152 cubic feet, whilst the volume produced by the combustion of hydrogen is 457 cubic feet. From this data the volume required for the combustion of an hydrocarbon can be computed when the composition of such is known. For instance, the lightest hydrocarbon (Methane CH_4) is composed of 75 per cent carbon and 25 per cent. hydrogen, by weight; hence the combustion of one pound of methane requires: $(152 \times .75) + (457 \times .25) = 233.25$ cubic feet of air.

When carbon is caused to burn with an adequate supply of air, it evolves 14,600 B.Th.U. per pound of fuel, and produces the gas carbon dioxide CO_2; and when the supply is insufficient it burns with one atomic proportion of oxygen only, and evolves 4,400 B.Th.U. per pound, with the formation of carbon monoxide CO. The complete combustion of hydrogen will evolve 62,000 B.Th.U. per pound when all the heat is absorbed, and the product is condensed to water H_2O, but when the combustion takes place in combination with other gases, as in the practical operation of a boiler furnace, the burning hydrogen must, necessarily, pass off as a gas, which reduces the total evolution of heat to 53,000 B.Th.U. Under perfect conditions of combustion, it is evident that one pound of methane will evolve $(14{,}600 \times .75) + (62{,}000 \times .25) = 26{,}450$ B.Th.U., but under the practical operation of a boiler furnace, using solid fuel, the perfect combustion cannot be caused to take place for various reasons, as hereafter referred to.

In the operation of a furnace by solid fuel, it is necessary to create a draft by means of a chimney, for the drawing of air for combustion; and to ensure a good draft the gases ascending the chimney must be comparatively lighter than the incoming air, which necessitates the temperature of such being greater. Under ordinary conditions, the temperature of the chimney gases are from 300° to 600° F., and consequently a comparatively large amount of sensible heat is passed up the chimney without the performance of work. It has been claimed that this lost heat may be avoided to a large extent by the use of steam blast beneath the furnace grate, but this method also possesses a number of disadvantages.

(1) It generates water gas from the fuel, and the water gas, after combustion, absorbs heat from other gases to prevent it from condensing in the chimney.

(2) It causes a comparatively large amount of free carbon to be driven off as smoke.

(3) It is wasteful in steam, and a comparatively large proportion of heat units which were originally absorbed from the furnace by the water, is given up beneath the grate of the furnace.

The greatest loss is undoubtedly due to imperfect combustion of the carbon, and immediately after a charge of fresh coal the volatile matter or hydrocarbons are driven off and only partially consumed owing to an inadequate supply of air, resulting in the formation of smoke. In order to prevent the loss of these gases as much as possible, a full supply of air is essential, and when the hydrocarbons have passed off, the same proportion of air is largely in excess to that required for the combustion of carbon; hence the carbon passing from the furnace is largely diluted with atmospheric air, and is, consequently, lowered in value accordingly.

VAPORIZATION: In comparing the efficiency of solid and gaseous fuels on a steam boiler, it is necessary to be acquainted with the facts of vaporization by the application of heat. In the first place the value of a heating agent is rated by the British Thermal Unit, which is "*the amount of heat required to raise one pound of water one degree Fahrehehit.*" When the temperature of water has been raised to the boiling point, or 212°F., the temperature remains constant and the heat is absorbed to convert the water into steam. This heat is known as "*the latent heat of vaporization,*" and is the amount required to change one pound of a liquid to a gas without change in temperature. The latent heat of steam is 967 B.Th.U.; hence to change one pound of water at 212°F. to one pound of steam at the same temperature, it requires 967 B.Th.U. being absorbed by the liquid. Assuming that the temperature of water entering the boiler is 60°F., the amount of heat required to raise one pound to 212°F. is $212-60=152$ B.Th.U. and to convert the water into steam it requires 967 B.Th.U.; hence the total amount is $152+967=1{,}119$ B.Th.U.

HORSEPOWER: The generating power of a boiler is rated by the standard of evaporation, which is commercially known as the *horsepower*. This standard may be stated as "*The evaporation of 30 pounds of water from a feed water temperature of 100°F. into steam at 70 pounds per square inch gauge pressure.*" In the calculation of horsepower it is necessary to reduce from and at 212°F. per pound of combustible, owing to different pressures and feed water temperatures at which boilers are operated. The actual evaporation of 70 pounds pressure is equal to $\frac{70-1}{2}=34.5$ units of evaporation, or 34.5 pounds of water evaporate to steam from a feed water temperature of 212°F. It is evident, then, that the boiler horsepower is equivalent to $967\times34.5=33.360$ British Thermal Units.

FUEL EFFICIENCY: The efficiency of a boiler is "*the ratio of heat utilized in evaporating water to the total heat supplied by the fuel.*" In computing this with a solid fuel the weight of the fuel used is ascertained and the ash and unburnt matter allowed for so that the amount of heat that should be evolved can be calculated. The heat expended in the generation of steam is then calculated from accurate observations of weight and temperature of feed water, and gauge pressure of steam; from which the heat absorbed is computed.

With this data the efficiency of a boiler can be obtained from the following formula:—

$$E=\frac{100\,S}{F}$$

in which S = the heat utilized in steam generation,

F = the heat evolved from the furnace.

For instance, if the heat utilized is 180,000,000 B.Th.U., and the amount evolved from the furnace is 300,000,000 B.Th.U., the efficiency of the boiler is:—

$$\frac{100\times180{,}000{,}000}{300{,}000{,}000}=60 \text{ per cent.}$$

The greatest proportion of the 40 per cent. loss is due to deposits of soot on the furnace plates and tubes, dilution of the gases by nitrogen, and to radiation.

The coals most frequently used for steam generation on a large scale are of the bituminous class, and in installations where stoking machinery can be employed, the fuel is generally the most economical. In small steam generators, such as used in the industries referred to on page 137, the class of coal is usually anthracite or coke, owing to the high percentage of carbon, low percentage of ash, and a comparatively small amount of smoke or flame when burning.

Figure 87

Assuming that the composition of these fuels is 90 per cent. carbon, the remainder of which is nitrogen, sulphur, ash, or other incombustible, the theoretical amount of heat capable of being evolved from one ton (2,000 pounds) will be as follows:—

$$(2{,}000\times.90)\times14{,}500=26{,}100{,}000 \text{ B.Th.U.}$$

Under the average conditions of a boiler furnace, the amount of heat lost by the chimney draft and incomplete combustion is approximately 30 per cent., which makes the total heat given up to the boiler as:—

$$26{,}100{,}000\times.70=18{,}270{,}000 \text{ B.Th.U.}$$

In taking the efficiency of the boiler as 60 per cent., as in the previous example, the total heat utilized in the generation of steam is:—

18,270,000×.60=10,960,000 B.Th.U.

The average cost of these fuels at the time of writing may be taken as $13.50 per ton, to which it is necessary to add $1.50 for haulage and storage, so that its use is equivalent to $15.00 per ton, or 730.666 B.Th.U. per dollar.

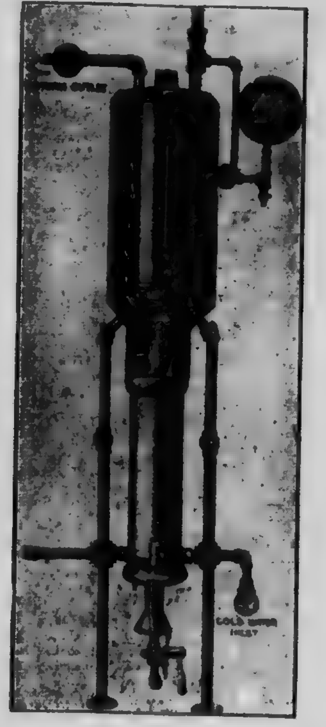


Figure 88

By the employment of a boiler heated by manufactured gases, the heat evolved can be concentrated on to a given point at which it is the most effective in steam generation, and loss by radiation can be practically avoided owing to the cleanliness of its use enabling the steam generator being placed in a position where the steam is desired, and thereby avoiding a piping system. With the admission of gas at a given pressure, the necessity of flue draft is eliminated, and the admission of air can be regulated to effect perfect combustion with a given quality of gas. Under favourable conditions the boiler flues and burners combined will give an efficiency of 95 per cent. of the total heat of combustion of the gas.

When gas is consumed on a large scale, as in this case, a special rate can usually be obtained from distributing companies at a small percentage above manufacturing cost. This rate may vary somewhat in different localities, and in medium sized towns a rate between 90 and 95 cents could be obtained under present conditions. Assuming that the rate is 90 cents net per 1,000 cubic feet, of gas with a calorific value of 590 B.Th.U. per cubic foot, which is the standard adopted in many towns, the heat units utilized in steam generation per one dollar of expenditure will be:

$$590 \times 1.111 = 655.490 \text{ B.Th.U.}$$

The expenditure of fuel according to these computations is approximately 10 per cent. greater by the use of gas, but the advantages gained in other respects more than offset this. The figures apply, of course, to manufactured gases, and where natural gas can be obtained, the rate per 1,000 cubic feet is considerably less and invariably is more economical than either coal or oil for all purposes

GAS-FIRED BOILERS: The application of gas has been made to boilers of various designs, but for industrial use the tubular boiler is generally the most suitable. The necessary fittings and boiler mountings are in common with those of boilers used for solid fuel, but for efficient operation it is advisable to equip such with an automatic feed water and gas control, which are actuated through link mechanism by the steam pressure. The type of boiler which is the most suitable for any one particular industry is a subject too broad to be discussed in a work of this kind, and, in general, it may be said that where power is desired in compact form, one of the most efficient of which the writer is acquainted with, is shown in Fig. 87, whilst for small units a very suitable design is illustrated in Fig. 88.

ANALYSIS OF COAL: The composition of coal is carbon, hydrogen, ash, moisture, and traces of sulphur, nitrogen, and iron, or other metallic compounds in varying proportions. In order to obtain economical results in the conversion of coal to gas, or for a special industrial purpose, it is advisable to know the nature of the substance, for which purpose a chemical analysis is required.

MOISTURE: The first determination made is for the percentage of moisture and this is effected by finely pulverizing a sample of coal and placing an accurately weighed portion in a stoppered U-tube, the weight of which has been previously ascertained. A second U-tube filled with pieces of calcium chloride is then carefully weighed after the air contained therein has been displaced by gas. The tube containing the sample of coal is placed in a beaker of water kept at boiling point, and beyond the weighted calcium chloride tube there is a smaller calcium chloride tube which prevents the absorbing of moisture from the air into the weighed tube. A current of coal gas, free from moisture, is then passed through the tubes, which carries the moisture from the coal with it to the weighted calcium chloride tube, where the moisture is absorbed. After two or three hours' continuous heating of the coal, the moisture therein should have all been driven off into the calcium chloride tube and the tube is disconnected and accurately reweighed. The increase in weight shows the moisture absorbed, and the percentage thereof in the coal by computation.

A second method, which may be used to corroborate the former, is to place a sample of coal in an open oven, heated to about 220°F., or just above the vaporizing point of water. The coal should first be accurately weighed in a small crucible, the weight of which is known, and should be taken from the oven and re-weighed about every two hours. After repeated tests it is found that the weight of the coal increases, and that no constant weight is obtained. The increase of weight is attributed to the slow oxidation of iron compounds, or by the absorption of gases into the pores left vacant by the expulsion of moisture; and, consequently, the lowest weight obtained is taken for the moisture determination.

VOLATILE MATTER AND COKE: The test for volatile matter is made by driving such off by the application of heat, and comparing the weight before and after the expulsion. An accurately weighed portion of finely pulverized coal is placed in a thin even layer at the bottom of a platinum crucible, and the crucible and coal accurately weighed without the cover. The crucible is then loosely covered and placed in an upright position in an iron ring bound round with platinum wire to prevent direct contact between the iron ring and platinum crucible. A bunsen burner is then applied to the bottom of the crucible, and it should be noted that at each test the length of flame and position of crucible is the same, so that the establishment of similar conditions will render the final results comparable. About one minute after the gas ceases to issue from beneath the lid, the bunsen flame is removed, and the crucible placed in a dessicator for a few minutes to cool such to normal conditions, and finally re-weighed without the cover. The loss in weight represents the volatile matter, from which the percentage of coke is obtained by difference. Assuming the conditions are as follows:

Weight of crucible and coal.......................400 grains

Weight of crucible	360 grains
Weight of coal	40 grains.

Weight of crucible and coke	390 grains
Weight of crucible	360 grains
Weight of coke	30 grains.

The weight of volatile matter lost is, therefore, 40......30 = 10 grains; and the percentage thereof is:—

$$\frac{100\times10}{40}=25.00,$$

whilst the 75 per cent. difference represents the coke.

ASH: The percentage of ash, or inorganic matter, is a very important item in the quality of coal or coke, and its determination is one of the most important in many processes. The constituents of this matter is iron oxide, silica, alumina, lime and sulphides in varying proportions, and traces of magnesia, potash, or other metallic compounds. These substances fuse together to form a metallic-like residue, which may differ somewhat according to the respective percentages of the constituents. The harder masses are usually red or reddish-brown, and have an iron base.

To determine the amount of ash in coal or coke, a sample is pulverized, and a weighed portion placed on apiece of platinum foil bent over a glass rod to form a vessel or boat for the reception of the coal. Previous to placing the fuel in the boat, the platinum is ignited to effect a thorough cleaning thereof, and after cooling, it is accurately weighed and finally the boat and fuel weighed together. The fuel is arranged in the bottom of the boat at a depth of about one-eighth of an inch, so that the heat is uniformly distributed to effect complete combustion of the carboneous matter, and the boat is placed on one end of a glass or porcelain combustion tube of about one inch in diameter and two feet long. The other end of the tube is connected to an aspirator which is adjusted to draw a steady flow of air through the tube to effect combustion of the carboneous matter. The tube is then heated to redness over a bunsen burner, or in a combustion furnace for 6 or 8 hours; care being taken to effect a uniform distribution of heat on the surface of the boat. After the combustible matter has been entirely consumed, the heat is cut off and the boat removed from the combustion tube and cooled in a desiccator. It is then accurately weighed and replaced in the tube for 30 or 40 minutes' further heating; after which period it is again cooled and re-weighed. If the two weights correspond, it is evident that the combustible matter has all been driven off, and the percentage of the ash can be computed from the respective observations.

For instance, if the conditions are as follows:—

Weight of Boat and Coal	150 grains
Weight of Boat	100 grains
Weight of Coal	50 grains

Weight of Boat and Ash	103 grains
Weight of Boat	100 grains
Weight of Ash	3 grains

The amount of Ash is $$\frac{100\times3}{50}=6 \text{ per cent.}$$

This is a common example of a good class of coal, and the amount of ash in a coke from the same coal which concentrates to 75 of its original weight, as in the volatile matter determination, is as follows:—

$$\frac{100\times6}{.75}=8 \text{ per cent.}$$

SULPHUR: The presence of sulphur in coal may occur in different forms, as metallic sulphides, sulphates or organic matter. The first two of these are content in the coal and remain in the ash which is concentrated therefrom; whilst the latter form may be divided into those which pass off in volatile matter, and those which are oxidizes to SO_3 by combustion of the coke.

In determining the total amount of sulphur, a finely powdered coal is intimately mixed with sodium chloride and potassium nitrate in a proportion of 1 to 20, respectively. The mixture of chloride and nitrate is made up of two parts of the former to one of the nitrate by weight. When the coal and chemical reagents have been thoroughly mixed, it is fed into a platinum crucible in very small portions while heat is applied very gently. The source of heat should be from an *Argand Spirit Lamp*, in preference to a gas flame, to prevent the possible absorption of sulphur from burning coal gas. The hot crucible causes deflagration of the mixture, and when the whole sample has been charged and the deflagration ceases, the residue is dissolved in water and a slight excess of hydrochloric acid is added to the solution. The acid solution is then heated for 20 or 30 minutes, which precipitates the metallic compounds as chlorides. These salts are filtered off, and an excess of barium chloride added to the filtrate, which brings down the sulphur as barium sulphate. This is filtered off and the salt thoroughly washed. It is then transferred to a crucible and ignited, which consumes the filter paper and evaporates any chlorides or water. After the residue has been cooled in a desiccator it is weighed and the percentage of sulphur computed from the observations.

The composition of barium sulphate is according to the formula $BaSO_4$. and the percentage of sulphur therein is approximately 13.74; therefore the weight of the residue must be multiplied by .1374 in order to determine the amount of sulphur.

Assuming that the weight of the sample of coal is 25 grains, it will be necessary to add 20 times this weight of sodium chloride and potassium nitrate, or 500 grains. If the residue weighs 2.75 grains, the amount of sulphur therein is $2.75\times.1374=.37785$ grains; and the per centage thereof is:—

$$\frac{100\times37785}{25}=1.51 \text{ per cent.}$$

It is frequently desirable to know in what form the sulphur is present in the coal, for which it is necessary to make determinations for the percentage in the ash and coke respectively, and deduct those from the total sulphur to obtain the difference which is present in the volatile matter.

The ash is obtained as previously described and is boiled in hydrochloric acid solution, which precipitates the metallic compounds as chlorides and dissolves the sulphur as sulphuric acid. The precipitate is then filtered off, and the sulphur precipitated from the fitrate with barium chloride as in the previous example.

The sulphur content in the coke is determined by combustion in which the sulphur is oxidized to SO_2. This determination is somewhat similar to the ash determination, and consists in heating a weighed portion in a platinum boat in a combustion tube and therein reducing the coal to ash by combustion. The gaseous products are aspirated as in the previous case, but in the path of the gases there is located a bulbed U-tube containing a definite quantity of standard solution of iodine. This solution absorbs the SO_2 according to the reaction $I_2 + 2H_2O + SO_2 = H_2SO_4 + 2HI$. The excess of iodine is then determined by a standard solution of sodium thiosulphite, and the amount converted to sulphuric acid by the SO_2 is obtained by difference.

If the sulphur in the ash and coke are then added, and the product deducted from the total sulphur obtained in the first test, the difference gives the sulphur in the volatile matter of the coal, from which the respective percentages may be computed.

NITROGEN: One method which is widely used to ascertain the percentage of nitrogen is by heating finely powdered coal with concentrated sulphuric acid in the presence of manganese dioxide. The reaction causes the carbon and organic matter to be completely destroyed, and converts the nitrogen into ammonium sulphate. The solution is then titrated by a sodium hydrate solution, and the contents of the flash distilled for the evolution of ammonia. The ammonia is led into a standard solution of sulphuric acid and the amount of acid neutralized observed, from which the nitrogen is computed.

In this determination the proceeding is as follows:—

About 1 gram of coal is weighed out and heated for 30 minutes in 25 to 30 cubic centimeters of concentrated sulphuric acid in a flask *f*, Fig. 89. After this period 5 grams of manganese dioxide is added, and the solution boiled for 45 minutes, after which 5 grams more of the dioxide is added, and the whole heated for 45 minutes longer. The solution is then allowed to cool and an excess of sodium hydrate added, the latter being made by dissolving 1.5 ounces of the salt in water. The contents of the flask are then distilled, when the ammonia passes off through the condenser *c* and into the receiver *R*, into which a definite quantity of standard sulphuric acid solution has been placed. A U-tube *t* is located beyond the receiver and also contains standard acid to neutralize any ammonia which may escape from the receiver. When distillation is completed the apparatus is allowed to cool for about 20 minutes previous to disconnecting, and finally the contents of the receiver and U-tube are poured into a beaker and the amount of acid neutralized carefully observed. The number of cubic centimeters are then multiplied by .014 gram, from which the percentage can be readily obtained.

Assuming that 3 cubic centimeters were neutralized, the weight of nitrogen would be $.014 \times 3 = .042$ gram, and if the weight of the coal taken was exactly one gram, the percentage is 4.20.

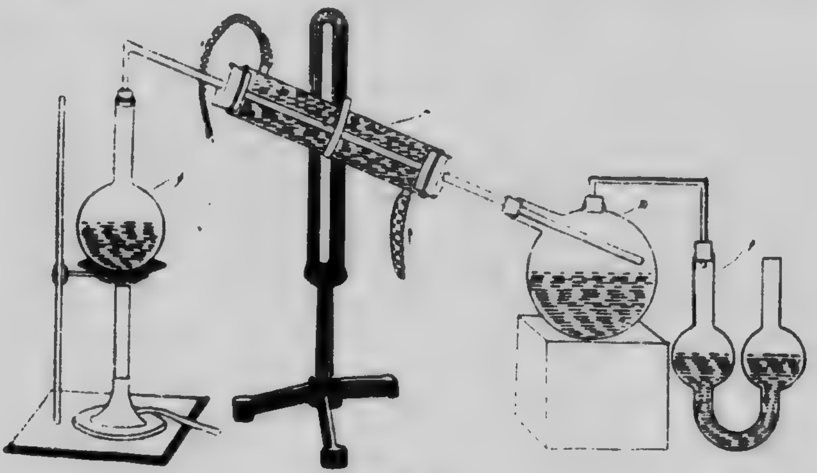


Figure 89

COMBUSTIBLE MATTER: The remainder of the coal is practically carbon, hydrogen and oxygen, and the amount thereof can be obtained by deducting the total impurities. The first two elements are combustible, whilst oxygen is a combustion supporter only and has, therefore, no heating value. When coal is heated, the oxygen combines with the hydrogen for combustion and reduces the percentage of the latter element accordingly. This reaction produces water vapor and requires two atoms of hydrogen to one of oxygen; and as the respective gravities are 1 to 16, the respective proportions by weight are one-eight to one. It is evident, then, that by deducting one-eight of the percentage of oxygen from the percentage of hydrogen, the net amount of hydrogen which can be recovered is obtained; for instance, if the percentage of hydrogen is 5.50, and that of oxygen 7.20, the unoxidized hydrogen is

$$5.50-\frac{7.20}{8}=4.40 \text{ per cent.}$$

Of these three elements it is necessary to determine two only by analysis, when the third can be obtained by difference. As the carbon and hydrogen are combustible, these two are determined by effecting combustion under conditions by which the products therefrom can be accurately measured. The analysis is illustrated with reference to Fig. 90.

About 5 grams of finely powdered coal is placed in a small platinum boat, and the boat introduced into the combustion tube *t*........*t'*, near the end *t*. The said tube is made of hard Bohemian glass, and is about 30 inches long, and from

5/8 to 3/4 inches in the inside diameter. Previous to placing the tube in its position, it is filled to about 24 inches from the end t' with dried cupric oxide. The end t where the coal is located is connected to an appartus O for transmitting oxygen or air to support the combustion of the coal; and in the path of this fluid there is located a jar J containing potash for the removal of carbon dioxide, and a pair of U-tubes C and C' containing calcium chloride for the removal of moisture At the other end of the apparatus there is provided a U-tube C'', which contains calcium chloride, the weight of which has been previously ascertained; and beyond this tube there is a bulb b which contains potash, the weight of which must also be known; and finally there is a guard tube G filled with calcium chloride to prevent loss of water from the potash.

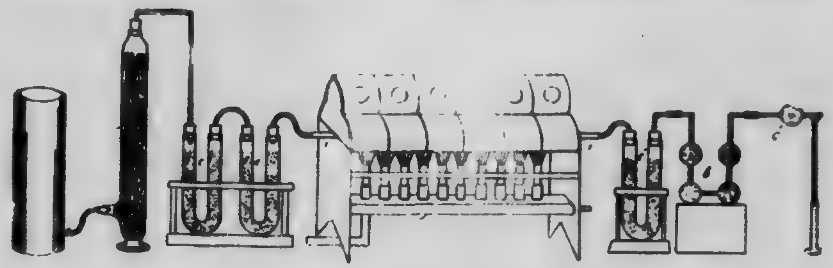


Figure 90

The combustion tube is supported in a gas furnace F, and the part of the tube that contains the cupric oxide CuO is heated to redness. The end of the tube containing the boat of coal is then gradually heated so that the volatile matter is driven off from the coal, and this, on passing through the red-hot cupric oxide, takes up oxygen therefrom for combustion. On passing through the apparatus the water vapor resulting from the combustion of hydrogen is absorbed by the calcium chloride in tube C'', and the carbon dioxide by the potash in bulb b, whilst the contents of guard tube G absorbs any moisture which may pass from the previous vessel. After about 50 minutes the volatile matter should be driven off and the dried air or oxygen is passed through the combustion tube from the vessels O, J, C, C', to burn the remaining carbon. The weight of vessels C'', B G are then ascertained and the increase in C'' calculated for the percentage of hydrogen, whilst the increase in vessels b and G gives the percentage of carbon.

Assuming that the weight of the coal is 5 grams, and that the increase of weight in the calcium chloride and potash vessels is 2.9 and 14.3 grams, respectively, the percentage of hydrogen and carbon will be as follows: The hydrogen burns to H_2O, and is, therefore, two parts hydrogen and one part oxygen. The atomic weights of these elements are 1 and 16, respectively, which makes the molecular weight as $2+16=18$; hence the weight of hydrogen is $\frac{2\times 2.9}{18}=.322$ grams; and the percentage thereof is

$$\frac{.322\times 100}{5}=6.44.$$

One atomic proportion of carbon burns with two atomic proportions of oxygen, and the atomic weights of the elements is 12 and 16, respectively; therefore the molecular weight of CO_2 is $12+32=44$. The weight of carbon in 14.3 grams of carbon dioxide is, therefore, $\frac{12\times14.3}{44}=3.9$ grams; and the percentage thereof is $\frac{3.9\times100}{5}=78.00$.

If the percentages of carbon, hydrogen, nitrogen, sulphur and ash are then added together, the difference gives the percentage of oxygen or other incombustible matter which it is not necessary to determine for practical purposes.

SPECIFIC GRAVITY: It may be said that the specific gravity of a body is "*The relationship existing between equal bulks of a substance compared with a standard substance.*" The standard substance for gases is hydrogen, and for liquids and solids it is distilled water at 39.2F, which is the temperature of its maximum density.

The specific gravity of coal is obtained by first weighing a sample in air, and then weighing it in water, and computing the difference according to the following conditions: When the coal is weighed in water, it loses weight equal to its own bulk of water; hence, by dividing the weight of coal in air by the loss of its weight in water, the specific gravity is obtained. For instance, if a piece of coal weighs 1,000 grains in air, and 237.8 grains in water, the loss of weight is $1{,}000-237.8=762.2$ grains; and the specific gravity is $\frac{1{,}000}{762.2}=1.312$.

CALORIFIC VALUE: The total heating or calorific value of coal may be calculated from the composition of the coal as determined by analysis, but for practical purposes it is usually more convenient to obtain such by burning coal in a combustion supporter and measuring the heat evolved through the medium of water.

A simple and efficient form of apparatus, which may be used for this purpose, is illustrated in Fig. 91, in which C is a copper cylinder adapted to receive the fuel, and is located on a brass base b surrounded by another copper cylinder C'. The fuel cylinder is perforated by very small holes to enable the gases from the combustion of the coal to pass into the water and give up the heat therefrom. The latter cylinder is also provided with a copper tube t, on which a cock is fitted so that when the two cylinders C' and C are fitted together and introduced into the water, the liquid is excluded from vessel C when the cock is closed, or admitted when the cock is opened. The combustion cylinders are located in a glass cylinder G, which is adapted to contain a definite quantity of water when filled to a certain mark.

In making a test by this apparatus, an accurately weighed portion of finely ground coal is mixed with ten times its weight of a mixture of one part nitrate of potash, and three parts of potassium chlorate; the said compounds having been dried previous to weighing. The mixture is then introduced into cylinder *C*, in conjunction with a fuse consisting of cotton wick which has been dipped in a solution of nitre and dried. When the fuse is fixed by packing the fuel around it, the temperature of the water is taken by a delicate thermometer, and the fuse then lighted and water cylinder *C′* fixed in its position with the cock on *t* closed before placing it in the water. In about one minute the fuse burns down the coal and produces combustion, and when such finally ceases, the cock on *t* is opened and the cylinder moved up and down for a few seconds to distribute the heat throughout the whole of the water. The temperature in then taken and the difference noted, from which the calorific value is obtained.

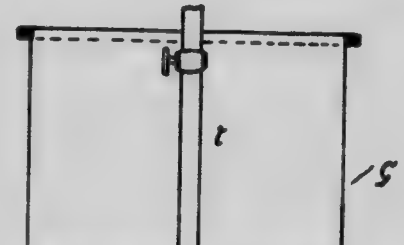


Figure 91

For convenient calculation it is common practice to use two grains of coal 20 grains of the mixture of nitrate of potash and potassium chlorate, and 1,937 grains of water, which corresponds to a mark on the glass cylinder at 60°F. These conditions are based on the assumption that 967 heat units are required to convert one unit weight of water into steam; hence, by dividing the weight of water by the weight of coal $\frac{1937}{2}=967$, it is evident that one grain of coal is equivalent to the unit weight of water, and the number of degrees at which the water is heated is equivalent to the pounds of water which one pound of coal will convert into steam. The number of degrees to which the water is heated, multiplied by the heat units per pound, will, therefore, give the heating value of one pound of coal in British Thermal Units.

OIL ANALYSIS:

SPECIFIC GRAVITY: The first determination which it is desirable to make in oil valuation is the specific gravity, and this can be approximately made by means of a hydrometer if desired. Oil, however, is frequently bought by weight, and a very accurate test is essential for which purpose a specific gravity bottle is used. These vessels are made to hold 50 or 100 grams of distilled water at 60°F., and are fitted in the neck with a perforated glass stopper, which enables the bottle to be filled with the total exclusion of air bubbles.

In the use of this bottle the oil is poured into the top of the neck and the stopper of the bottle inserted so that any air is driven out through the perforations in the stopper. The bottle is then thoroughly cleaned of all oil by means of a soft cloth, and the top of the stopper should be cleaned by the hand to prevent any absorbent material drawing air from the capilliary bore of the stopper and thus lowering the weight of the oil. The bottle and contents are then weighed, and the weight of the bottle deducted to obtain the weight of the oil. The specific gravity can then be determined at 60°F. by dividing the weight of the oil by the weight of an equal bulk of distilled water. For instance, if the bottle holds 50 grams of distilled water at 60°F., and the weight of the oil at the same temperature is 42.5 grams, the specific gravity of the oil is $\frac{42.5}{50} = .850$.

It should be noted, however, that the exact temperature of the liquids is very important in obtaining accurate determinations, and if the test cannot be made at exactly 60°F. the temperature should be carefully observed and a correction made by the co-efficient .0004, which is equal to one degree fahrenheit. It is evident that at a higher temperature the liquids expand and lower the weight of a given bulk accordingly; consequently the co-efficient should be added, whilst at a lower temperature it should be deducted. For instance, if the temperature of the oil is 70°F., it is necessary to add $.0004 \times 10 = .004$ to the result obtained by the weighing. Assuming that the previous test had been made at 70°F., the corrected specific gravity is $.850 + .004 = .854$; whilst at 50°F. it would be .846.

It may be stated this co-efficient should be employed in correcting large stocks of oil in tanks, as the atmospheric temperature affects expansion and contraction considerably, and by the application of the co-efficient the correct volume at 60°F. can be obtained.

FRACTIONAL DISTILLATION: The most important information as to value of an oil can be obtained by distilling the oil, and collecting in fractions about 10 per cent. of the original sample. In this operation about 250 grams of oil is placed in a 500 cubic centimeter flask, into which a thermometer is inserted with the bulb just below the delivery opening, as seen in Fig. 92.

On the delivery pipe of the flask there is located a condenser, made from a piece of wide bore glass tubing and two rubber stoppers, and through which a supply of water is constantly passed to bring down the vapors coming from the flask to a liquid. The distillation is colected in a series of test tubes, and the temperature noted at each collction. When the volatile matter has all been driven off, the solid residue or pitch is weighed, and should not be more than one per cent. of the original sample. The temperature of the oil should be regulated so that the distillate comes off gradually and falls from the condenser into the test tubes in drops. The collected samples can then be tested individually for specific gravity, acidity, or other information which it is desirous to know.

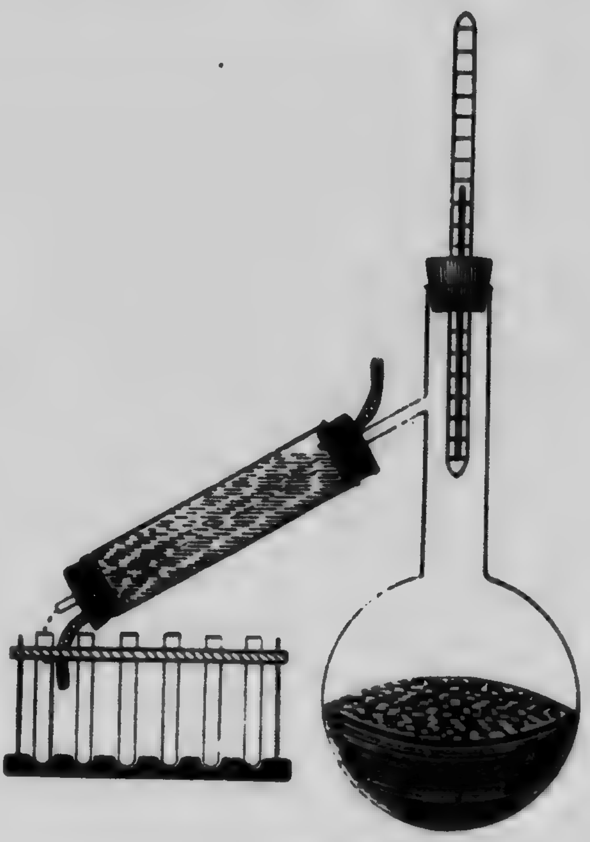


Figure 92

FLASH POINT: The flash point of an oil is "*The temperature at which the oil commences to give off sensible quantities of inflammable vapors.*" The determination of this point is a very important item, owing to the fact that oil transportation and fire laws associated with the storage of oil are influenced by it. It is evident that an oil with a low flash point is more dangerous to transport and store, and therefore great care has to be taken to prevent such from being brought near a heated atmosphere, or in the vicinity of sparks.

The flash point may be determined by various types of apparatus, but the Abel is probably the most common. This apparatus, Fig. 93, is constructed of copper and brass and confirms to accurate dimensions. The oil cup *C* is a cylindrical gunmetal vessel 2 inches in diameter, and 2.2 inches high to the supporting rim *R*. A bent wire *W* serves as a gauge for the height of the oil in the cup. A brass cover *C'* carries a thermometer *t* for registering the temperature of the oil in the cup, and also a test lamp *L* for igniting inflammable vapors. The lamp *L* is mounted on trunnions so that it may be oscillated, and it is provided with a plaited candle wick, and burns rape oil. The cover *C'* is provided with three rectangular holes adapted to be uncovered by slides *S* which moves in grooves, and has perforations in it corresponding to those in the lid. The slide also carries a pin which tilts the lamp in its movement, and turns the spout downwards into the holes it uncovers. The return movement of the slide to close the hole disengages the pin, and allows the lamp to swing back to its original position. In

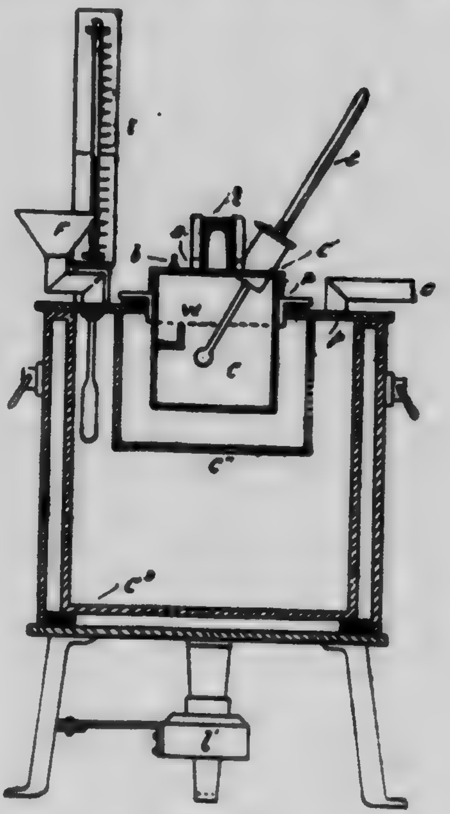


Figure 93

line with the lamp there is a white bead b on which the test flame reflects and provides a gauge for the adjustment of the size of the flame. The oil is heated through baths which consist of two flat bottomed copper cylinders C'' and C_3, fixed to a circular plate p. An ebonite ring prevents metallic contact between the oil cup and the bath. The outer bath is provided with a funnel F, an overflow O, and a thermometer t', and the whole outfit is surrounded by a copper jacket J resting on a cast iron tripod. Attached to one leg of the tripod there is a spirit lamp L' for heating the bath.

In making a test the apparatus is placed in a position free from drafts, and preferably in a room with green shades to restrict the light and permit a distinct reflection of the test flame on the white bead. When the apparatus is located in a suitable position, the bath is filled with water through the funnel F until it overflows at O; and the oil is poured into the cup until its surface is level with the wire gauge W. The temperature of the water when filling the bath should be approximately 130°F. The thermometer t is then inserted so that its bulb is just below the surface of the oil, and finally, the test lamp L is lighted. When the temperature of the oil reaches 66°F. the pendulum is set in motion so that its bulb passes over the entire surface of the oil, and the test should hereafter be made at every 1°F. rise in temperature. The oscillations of the pendulum serves as guide for applying the test, and it is good practice to slowly draw upon the slide while the pendulum is making the third oscillation, and close it during the fourth. When the oil vapors ignite with a pale blue flame, the temperature should be noted and taken as the *flash point*.

The aforesaid proceeding is usually sufficient for gasmaking or other industrial purposes, but it occasionally happens where very volatile and heavy oils are used for a special purpose. In testing the volatile oils it frequently happens that the temperature of the oil has been brought down by placing the sample in ice water previous to placing it in the oil cup of the testing apparatus, and in these cases the water bath which regulates the temperature of the oil must also be cooled by ice previous to applying heat. In applying the test for a heavy oil, it is advisable to fill the heating bath with a liquor more volatile than water, such as gas oil or water gas tar.

To obtain accurate results it is necessary to correct the test to atmospheric pressure. It is found that the flash point is elevated or depressed to an average of 1.6°F. for every inch rise or fall in barometer from the standard height of 30 inches; hence, if the test shows a flash point of 78°F., and the barometer is 30.8 inches, the correct point at normal pressure is $78\times(30.8-30.0)\times1.6=76.72^\circ$F.

The Abel's test is employed by several countries as a standard for oil laws, and when the flash point is below 73 at normal pressure, it is classified as being highly inflammable, and its transportation and use is restricted without special precautions.

GAS ANALYSIS.

INTRODUCTION: The determination of the elements of a gaseous mixture constitutes a special branch of chemical analysis, and frequently involves the use of special apparatus. The expansion and contraction of gases is influenced greatly by atmospheric pressure and temperature, which necessitates the use of great care in observing the conditions and the employment of special formula to obtain accurate results.

The most accurate methods of analysis involves the use of mercury as the confining liquid, and they also require elaborate apparatus which calls for a large amount of manipulating skill. This class of apparatus, whilst being desirable for experimental work, is not necessary for gas analysis for industrial purposes, and more simple means are in use, the elements of which will be hereafter described.

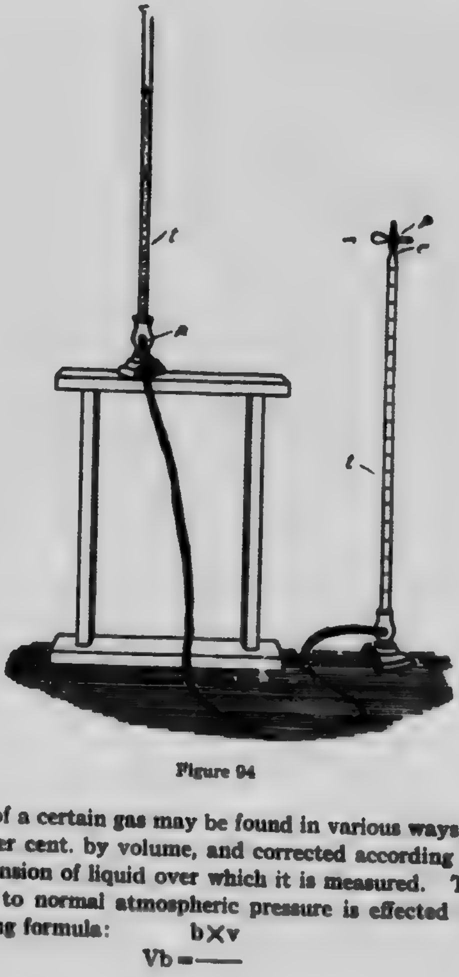


Figure 94

The quantity of a certain gas may be found in various ways, but in all cases it is expressed in per cent. by volume, and corrected according to the pressure, temperature and tension of liquid over which it is measured. The reduction of the volume of gas to normal atmospheric pressure is effected by the employment of the following formula:

$$Vb = \frac{b \times v}{760}$$

in which b = barometric pressure.
v = volume of gas.
Vb = volume of gas at 760 millimeter pressure.

The expansion of a volume of gas according to temperature conditions is at the rate of $\frac{492}{1}$ for every 1°F. rise; hence, by observing the correct temperature at which the test is made, and correcting the volume by the fraction, the volume at normal pressure is obtained.

ANALYTICAL APPARATUS: The absorption of a gaseous constituent is carried out by apparatus which serves for holding the absorbing liquid, and for bringing the gas in contact with it after being accurately measured. The gases remaining after absorption are then carried over into the measuring tube and the volume noted, from which the volume absorbed is obtained by difference. One of the most widely used apparatus is based on this principle, and consists essentially of a measuring apparatus or *burette*, and an absorbing vessel or pipette. The burette is illustrated in Fig. 94.

The tubes *t* and *t'* are made of glass, cemented in slots of semi-circular wooden feet, and are connected together by three or four feet of india-rubber tubing. The tubing is divided in the centre and joined by a piece of glass tubing so that the connection may be temporarily broken to facilitate cleaning of the tubing. The bottom of the tubes *t* and *t'* inside the feet are bent at right angles, and conically drawn out for the reception of rubber tubing, and the projecting ends are corrugated to enable the rubber to be tightly attached and bound by thin copper wire. The tube *t'* terminates at the top in a capilliary tube *C*, from 1/2 to 1 millimeter internal diameter, and approximately three centimeters long. On the capilliary tube a piece of india-rubber tubing is secured by copper wire, and is adapted to be closed by means of a pinch cock *p*. The measuring tube *t'* is graduated to 100 cubic centimeters, and each C. C. is divided into fifths. The tube *t* is not graduated, and is open at its upper end to enable liquids to be poured therein.

In the operation of the burette the two tubes are filled with water and then moved up and down a few times to eliminate any air which may be enclosed therein. The measuring tube is then connected to the gas supply by means of tubing, and the air driven from it by raising the pressure tube *t*. The said tube is then grasped by the left hand; the rubber tube closed at *R*; the contents of tube *t* poured out; and the pinch cock *p* opened, which causes water to flow from the measuring tube to the pressure tube and draw gas with it. When the measuring tube is filled with gas, the pinch cock is closed and the gas supply disconnected; and after waiting a few minutes for the water to settle, the tubes are raised and lowered until the level of water is the same in each tube. The gas is now under atmospheric pressure, and its volume is read off. The volume at this stage should be slightly more than 100 cubic centimeters, and to adjust it to exactly 100 C. C., the gas is compressed to slightly less than the volume required by raising the pressure tube and then closing the rubber tube at the base of the measuring tube with the thumb and first finger of the left hand. The pressure tube is then placed on the table; the measuring tube raised by the right hand to the level of the eye, and the rubber tube carefully opened until the gas stands at exactly 100 C. C. The rubber tube is again closed and the pinch cock opened for a second to allow excess pressure to escape and leave the volume of gas at 100 C. C. atmospheric pressure.

The *pipette* in which the liquid is absorbed is illustrated in Fig. 95, and consists of bulbs *b* and *b'* and a thick walled tube t'', which is known as the capilliary tube. The bulb *b* is somewhat larger than *b'*, and their respective capacities are about 150 and 100 cubic centimeters, so that when the 100 C. C. of gas is brought into the larger bulb, sufficient space is allowed for the absorbing fluid. The pipette is usually screwed on to a wooden frame as shown to permit easier manipulation and reduce the liability of breakage. At the outlet end of the capilliary tube, a short piece of india-rubber is fastened by means of thin wire to enable convenient closing of the outlet by the thumb and forefinger; and located behind the capilliary tube there is a scale which is generally made of white procelain.

The apparatus thus described represents the simplest form, and serves to illustrate the principles of gas analysis in the most direct manner.

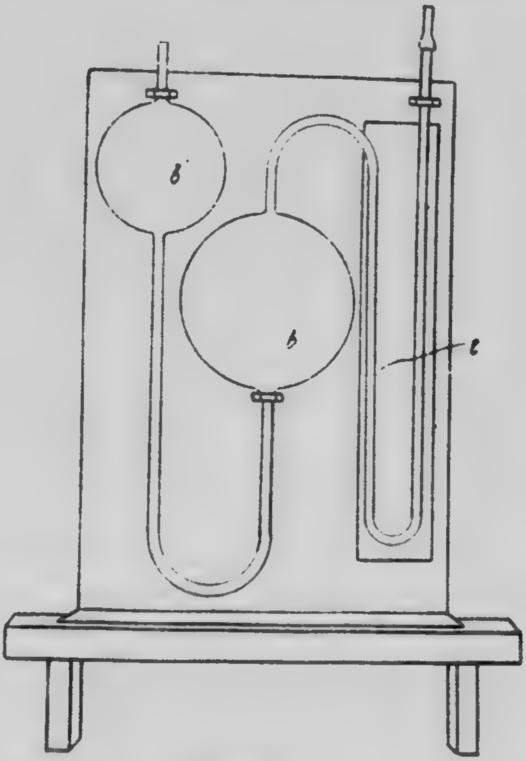


Figure 95

In the manipulation of this apparatus the burette is attached to the pipette by means of capilliary tube t^3 and rubber tube R', Fig. 96. In order to avoid the enclosing of air during this connection, the rubber tube is filled with water previous to the insertion of the tube t^3. The latter tube has an internal diameter of about .5 millimeter only, and on allowing the water in the rubber to expand, the tube t^3 also becomes completely filled with water. The rubber tube of the pipette is then squeezed between the thumb and first finger of the right hand, and whilst thus compressed free from air, the capilliary tube is inserted in it.

The pressure tube t of the burette is then raised and the pinch cock opened; which causes gas to pass into the absorption pipette. It occasionally happens that a small amount of air is admitted when the tube t^3 is inserted in its position, but this should always be separated from the gas in the measuring tube of the burette by careful manipulation. If the amount is not more than 10 millimeters, it may be disregarded in practical determinations, as the error is equivalent to about .03 cubic centimeter only. If however, the air is present in larger quantities, the gas should be brought back to the burette by lowering tube t, and the tube t^3 re-connected. When a satisfactory condition has been established, and the gas is passed over into the pipette, a small amount of water is allowed to follow it to clean the capillary tube of the absorbent liquid which it previously contained. The gas is now enclosed between the absorbent in the bulb of the pipette and the water in the capilliary tube, and the pinch cock should be closed and burette disconnected. The pipette is then shaken to neutralize the gases under analysis.

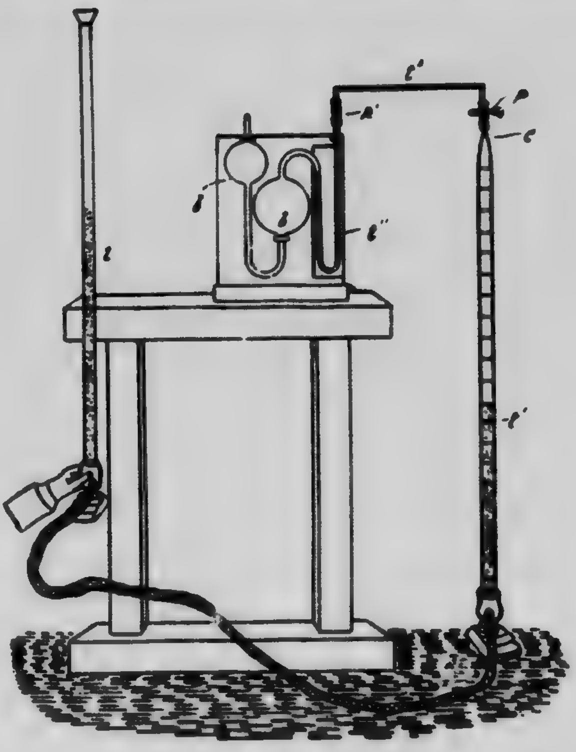


Figure 96

When a thorough absorption has been effected, the pipette and burette are re-connected, and the pressure tube placed on the floor to bring the remaining gases back to the measuring tube. The pinch cock is again closed; the pipette disconnected; and the volume of gases read off; from which the volume absorbed and percentage thereof is obtained.

The determinations usually made on gases distributed for commercial purposes are carbon dioxide CO_2, oxygen O_2, olefines C_2H_4, carbon monoxide CO, hydrogen H_2, methane CH_4, and nitrogen N_2, and a separate pipette containing and absorbent suitable for each gas should be used. After each determination, the pipette should be closed with cocks to prevent atmospheric contact with the absorbent and cause reaction therewith.

CARBON DIOXIDE: In proceeding with the analysis of gas, the aforesaid constituents are usually determined in the order given above, and their respective percentages generally increase in this order. The first determination to be made is carbon dioxide, and exactly 100 cubic centimeters of the gas is collected in a burette containing water which has previously been saturated with gas by leading a stream through it in a suitable vessel. The absorbent for carbon dioxide is caustic potash; and a suitable solution may be made by dissolving about 150 grams of the salt in 200 cubic centimeters of water. On passing the gas through this solurion, the absorption of CO_2 is almost instantaneous, and the volume neutralized can be read off on passing the gas back to the burette.

The carbon dioxide has no heat value, and the percentage in purified gas may vary according to the nature of the coal and the methods of purification; but should not be more than 1 per cent. by efficient operation of the manufacturing plant.

OXYGEN: A second pipette for the absorption of oxygen is then attached to the burette and the gas passed over. The absorbent for this gas is an alkaline solution of pyrogallol, and is made by dissolving 10 grams in 200 cubic centimeters of caustic potash solution of similar strength to that used in the CO_2 determination. The amount of oxygen is usually in the region of .05 to 1 per cent.

OLEFINES: The olefine determination is then made by passing the gas through fuming sulphuric acid or bromine water, after which it is necessary to again pass it through a caustic potash pipette to remove sulphur dioxide or bromine vapor. The percentage of olefines may be from 3.00 to 5.00.

CARBON MONOXIDE: The test for CO is then made by an ammoniacal solution of cuprous chloride. The solution is made by mixing 20 grams of the chloride with 100 cubic centimeters of water, in a flask in which two tubes are passed therein through a perforated cork, one of which extends nearly to the bottom of the flask, while the other extends just below the cork. A stream of ammonia gas is led into the liquid in the flask until the cuprous chloride is all dissolved, when the solution will assume a pale blue color. The stopper is then removed and the solution diluted to 200 cubic centimeters, previous to transferring it to a pipette. When the carbon monoxide is led into the pipette, it should be thoroughly shaken with the solution for three or four minutes before the gas can be completely absorbed.

HYDROGEN: The remaining gases are hydrogen, methane and nitrogen, of which it is necessary to find the first two by analysis and the nitrogen by difference. The determination of these gases is slightly different from the previous examples, and necessitates the use of modified apparatus. In the hydrogen test a tube t^4, Fig. 97, is placed between the gas burette and absorption pipette for the reception of a palladium sponge, which serves to occlude hydrogen. The said tube is about 4 millimeters internal diameter and 20 centimeters long.

The burette and pipette are joined to the palladium tube through the capilliary tubes C^4 and C^5, and the pipette is filled with water to *W* so that it may be employed to repeatedly pass through the palladium. In making the analysis, the gas in the burette is first mixed with an excess of air, and after the apparatus is connected together the beaker containing the palladium tube is filled with water at or near the boiling point. The cock K is then opened and the gas driven through the palladium three or four times. The hot water is then replaced with water at normal temperature and the gas again passed through the palladium to thoroughly cool it, and finally, the pressure tube of the burette is held so that the water in the pipette stands at *W*. The gas is then measured; the difference between the two measurements obtained; and the volume of hydrogen computed therefrom. This is usually from 45 to 55 per cent.

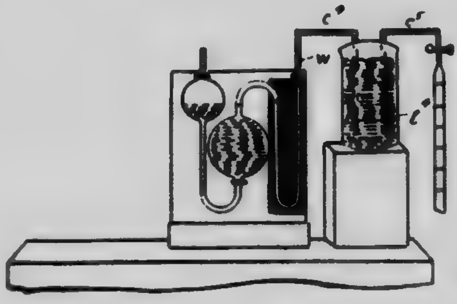


Figure 97

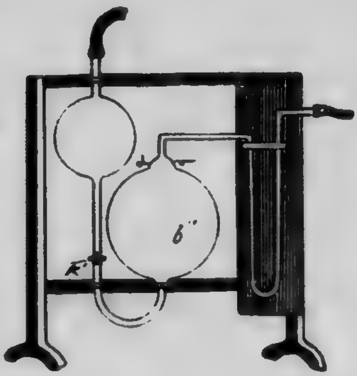


Figure 98

METHANE: The residual gases now consist of methane and nitrogen, and sufficient air is added to enable complete combustion of the methane. In the analysis of this gas it is necessary to use a special form of apparatus, known as an *explosion pipette*, which differs from the simple pipette in that it contains two platinum wires fused in the upper part of the bulb b'', Fig. 98, and is provided with a cock K′ to close connection between the two bulbs during explosion. In this case the bulbs are charged with mercury instead of water, which is driven over into the capilliary tube to a fixed mark by blowing through the rubber tube of the upper bulb. After the gas in the burette has been accurately measured, and the apparatus connected, the gas is transferred to the pipette, and the water from the burette made to follow it so that it just fills the capilliary tube without entering the bulb. The cock K′ is then closed and the gas lighted by a spark from an induction coil, after which the cock is opened and the products of combustion transferred to the burette and measured. The explosion pipette is then disconnected and replaced by a simple absorption pipette containing caustic potash, in which the products of combustion CO_2 is absorbed as in the carbon dioxide test previously referred to.

The volume of methane originally present in the mixture is equal to volume CO_2 absorbed as seen from the equation: $CH_4+2O_2=CO_2+2H_2O$.

The percentage of CH_4, which may be from 35 to 40, is added to those of the hydrogen, carbou monoxide, olefines, oxygen and carbon dioxide and the difference gives the percentage of nitrogen. The latter gas may be present in about 4.00 per cent.

FLUE GASES: A frequent analysis of chimney or flue gases is necessary for the efficient operation of any industrial process where fuel is consumed in any form. This is best obtained by a portable apparatus, which can be operated for a practically complete analysis at one time. One of the best and simplest designs of portable apparatus is the *Orsat*, or some modification thereof. This instrument is contained in a wooden case with removable back and front for convenience of transport. It consists of a tube *t*, Fig. 99, graduated to 100 C. C., and surrounded by a water jacket for the maintenance of constant temperature. The lower part of the graduation tube is sub-divided into one-fifths C. C. for greater accuracy, and is connected to a bottle *B* filled to about two-thirds with water. This is known as the levelling bottle, and is controlled by means of a pinch cock *P*.

The upper capilliary end of tube *t* is connected by thick-walled tubing to one end of the capilliary tube *C*, which is provided with a three-way cock *C'*, and stop-cocks *S*, *S'*, *S''*, S^3, connecting to absorption pipettes *A*, *A'*, *A''*, A^3, respectively. The three-way cock is adapted to connect the gas supply tothe burette or pipettes, or to put these vessels under atmospheric pressure. The pipettes are U-shaped vessels, the front limbs of which are filled with glass tubes adapted to expose a large surface of the absorbent when the gas is admitted.

These vessels are filled with an absorbent suitable for the gases to be analyzed for instance, in the analysis of flue gases, the pipette *A* is filled with caustic potash solution for the determination of carbon dioxide CO_2; *A'* with pyrogallate of potash for *oxygen* O_2; and *A''* with an ammoniacal solution of cuprous chloride for *carbon monoxide CO*. The pipette used for the absorption of oxygen must be protected from the oxygen of the atmosphere, and this is done by connecting the open limb of the pipette *A'* to a bottle *B'*, into which the connecting tube is sealed in water. In flue-gas analysis the fourth pipette A^3 is also filled with cuprous chloride as a check on the third for determination of CO, and both the third and fourth are filled with copper wire spirals instead of glass tubes to insure purity of the absorbent. In very accurate tests it is necessary to have the open limbs of these two vessels protected from the atmosphere, as in the case of *A'*.

In the manipulation of the apparatus the levelling bottle *B* is placed on top of the case, and the three-way cock *C'* opened to the atmosphere, which allows the graduated tube to be filled with water. The flow is stopped at a mark on the capilliary tube by the pinch cock *P*. The gas supply is then connected, and air from the conducting tube drawn out by connecting an india-rubber bulb or pump to the atmospheric connection of the three-way cock. The cock *C'* is then moved to put the gas in line with the burette *t*, and the levelling lowered bottle, which draws in the gas. The water in the burette is allowed to fall to slightly below the zero mark, after which the gas is cut off by the cock *C'*. The gas in the burette is then compressed by raising the levelling bottle until the water rises to above the zero mark, after which the pinch cock is closed and the bottle again lowered. The level in the burette is then brought to exactly zero by careful operation of the pinch cock. The three-way cock is then opened for an instant to bring the 100 C. C. of gas in the burette to atmospheric pressure. The gas is then driven into the first absorption pipette *A* for the determination of CO_2, by raising and lowering the levelling bottle a few times. After the first test, the level of the liquid in the vessel is adjusted to the correct height and the stop-cock *S* closed. The reading of the burette is then made by raising the levelling bottle until the contents are the same level as the water in the burette. The decrease in the volume of gas in the burette gives the percentage of CO_2. The second test for O_2 is similar to the former, and the third for CO is also similar, with the exception that after passing through the cuprous chloride the gas is again passed through the CO_2 pipette before measuring.

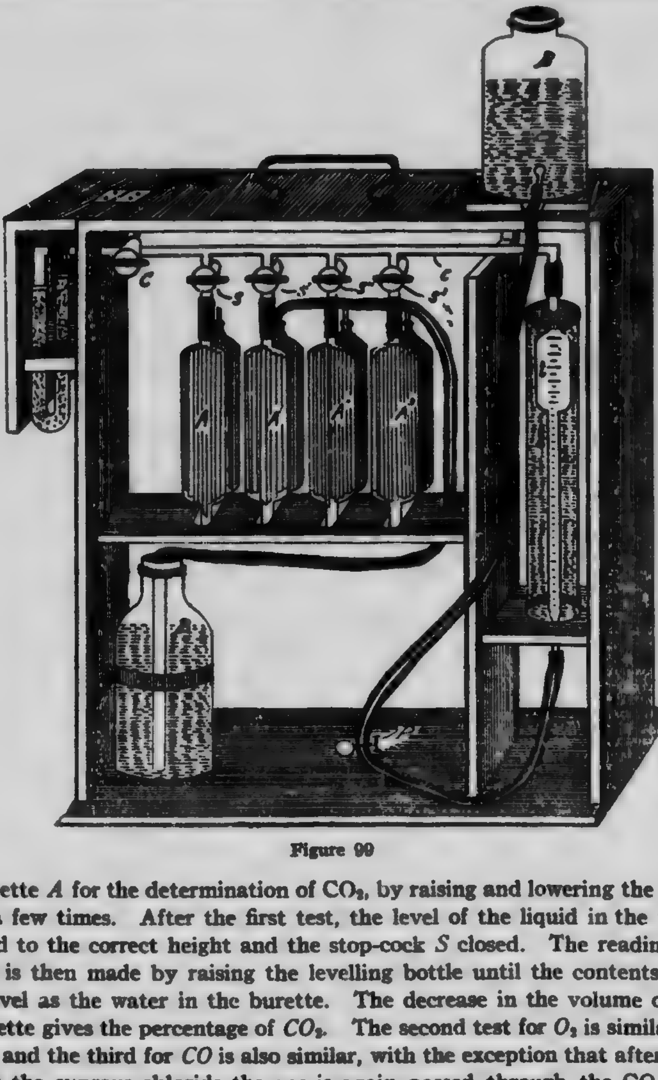


Figure 99

DOMESTIC GARBAGE: In the previous chapters it has been shown that fuels, either solid, liquid or gaseous, originate from carboneous matter, which has resulted from the slow decomposition of vegetable matter under various conditions of temperature; and that such matter has become dense by the pressure of the overlying strata during the course of ages. The best known products resulting from these conditions is coal, oil and natural gas, from which other fuels are developed.

It being accepted that these fuels originated from vegetable matter, it behoves us to go back to the origin for future developments, and consider to what extent this matter can be treated or consolidated into a combustible substance for industrial use. Whilst these remarks apply to lignite, peat, or other less concentrated fuels, they are chiefly intended to bear reference to *waste foods, or domestic garbage*, of which every individual contributes a portion daily.

The use of domestic garbage as a source of raw material for the manufacture of artificial fuel is a subject which is attracting much attention at the present time. This matter has previously been disposed of at a local destructor, or burned in a private incinerator; a fact which illustrates its combustible nature, and leads us to believe that by removing undesirable compounds, the matter can be consolidated into a carbon substance, which can be burnt in an open grate; whilst by fermentation it can be made to yield *industrial alcohol* on a commercial scale. The manufacture of alconol from foods has long been the chief source, but for general industrial use, the cost of raw material is the greatest difficulty, and the fuel cannot be manufactured to compare favourably with other fuels.

A brief description of the methods of obtaining alcohol from the commonest foods of life is given hereafter, and the methods are applicable to waste foods with slight modifications. The treatment of domestic garbage, according to these methods, would also have the effect of removing the undesirable volatile acids previous to consolidation of the solid residue into an artificial fuel.

ALCOHOL: The term alcohol as applied to the commercial product has reference to a series of organic compounds of analagous structure having a composition of hydrocarbon, in which one or more of the hydrogen atoms are replaced by a corresponding number of hydroxyl groups.

The most common compound of the alcoholic series, which is used for internal combustion engines is *methyl alcohol* $CH_3.OH$, which is obtained from the distillation of wood, and is frequently known as *wood alcohol*. Its boiling point is 150°F.

The original or *ethyl alcohol*, which is popularly known as spirits of wine, has a composition of $C_2H_5.OH$, and is obtained from the fermentation of sugar, according to the reaction $C_6H_{12}O_6 = {}_2C_2H_5.OH+2CO$, in which carbon dioxide is liberated. Its boiling point is 172°F.

The next compound in nearest relation to the former is *propyl alcohol* $C_3H_7 OH$, and is obtained from the fermentation of grapes. Its boiling point is 207°F.

The compound *butyl alcohol* $C_4H_9.OH$ is obtained from the fermentation of beets, and has a boiling point of 242°F.

A fifth compound which is of importance is *pentyl alcohol* $C_5H_{11}.OH$, and is obtained from the fermentation of potatoes. Its boiling point is 278°F.

In addition to the above there are several other compounds of the alcoholic series in which the percentage of carbon increases gradually, and the boiling point becomes higher accordingly, and consequently are of less value as a liquid fuel.

In this work the reference is intended to be applied to the use of domestic garbage or waste foods, and, as it would be impractical to give the chemical composition and alcoholic reaction of every food used in the necessities of life, the notes will refer to the most common, which may be stated as potatoes, beets, sugar, wheat, corn, rice, and other cereals.

ALCOHOLIC FERMENTATION: The term fermentation is applied to the spontaneous change undergone under certain conditions by an animal or vegetable under the influence of ferments, by which other compounds not originally present are found in the substance. The real reaction which produces fermentation is a subject of much investigation, and is yet shrouded in obscurity. It has been claimed that the action of ferments is due to the life and growth of minute cells of which they are composed. The germs of various ferments exist in the air, and whenever they find favorable conditions they develop and produce their characteristics effects. For instance, when a plant juice containing sugar is left exposed to the air it slowly undergoes a certain change and loses its natural sweet taste. This change may be considered to consist of breaking up the sugar and liberating carbon dioxide according to the equation:

$$\underset{\text{Sugar}}{C_6H_{12}O_6} = \underset{\text{Ethyl Alcohol}}{2\,C_2H_5.OH} + \underset{\text{Carbon Dioxide.}}{2\,CO_2}$$

This reaction is known as alcoholic fermentation, and can be caused to take place under proper conditions, but if the conditions are not conducted carefully, other fermentation ensues, resulting in the formation of acetic, lactic and butyric acids. The micro-organisms which constitute the ferments are of different kinds, and cause different kinds of fermentation with different products, and it is generally recognized that in order to develop the fermentation there must be present some compound which contains nitrogen. This element is present in all fruits and vegetable matter and consequently they readily undergo fermentation.

In this work the alcohol is the only liquid in which we are interested, and alcoholic fermentation only will be discussed. In order to produce this it is necessary to employ five agents, acting in different directions, and in the absence of any one the fermentation cannot take place. The agents referred to are sugar, water, a ferment, heat and air.

The *sugar* is present in various kinds of fruit and organic matter, and may be divided into *glucose* and *monosaccharides*, having the general formula $Cn(H_2O)$; and *disaccharides*, having the general formula $Cn(H_2O)n-1$. The sugars of the second class is cane sugar, and those of the first class are grape sugar, and the former can be resolved into the latter by hydrolysis. Before fermentation of sugar can take place, it is necessary to convert it into glucose by combining with two equivalents of water, after which the conversion readily takes place. The best proportion of sugar in an unfermented liquor is about 12 per cent.

The proportion of *water* employed in dissolving the glucose exercises considerable influence on the products of fermentation, as well as upon the time occupied by the process. The water employed should be clean; contain no organic matter, and only minute particles of mineral salts. The relative amount of water present in a solution is ascertained by means of a saccharometer.

The *ferment* is the substance undergoing decomposition, and when brought into contact with sugar, the atomic motion is communicated to the atoms of carbon, hydrogen, and oxygen, of which the sugar is made up; and the carbon divides itself between the hydrogen and oxygen in such a manner that two new compounds—alcohol and carbon dioxide are formed. The elements of the ferment take no part in the formation of these products, and act only as a stimulant which provokes the change without actually participating therein chemically. It may here be emphasied that it is the fermentation that produces the alcohol, and after fermentation, the hitherto diluted solution of sugar is now a solution of alcohol and water, from which the alcohol is recovered by distillation. The ferment commonly employed in all industrial operations is brewers' yeast, which is a frothy solution formed during the fermentation of worts of beer.

The proportion of yeast and sugar for rapid fermentation is five parts of the sugar to one part of the yeast, although the same quantity of yeast will ferment a considerable larger quantity of sugar by allowing longer periods. Whilst yeast may be claimed to have the greatest power of conversion of sugar into alcohol, it may be said that any nitrogenous substance will affect the conversion in a less extent when the sugar is in a state of incipient decomposition.

The *heat* of fermentation is an important factor in hastening or checking the process, and the lowest temperature at which the action is sustained is 60°F. it being more energetic and perfect as the temperature increases up to about 85°F., after which a higher temperature is liable to excite acid fermentation.

The effect of *air* is indispensable at the beginning of fermentation, after which it is of no use, and is likely to become injurious if action is continued. It is essentially an initial force, but when once the impulse has been given, it is no longer necessary, and should be excluded as carefully as possible in order to prevent acid fermentation.

In producing fermentation from the aforesaid agents, the initial object is to convert the sugar or starch into glucose, and then convert the glucose into alcohol and carbon dioxide. In order to do this it is necessary that the material to be treated should be got into a finely divided state or mash by means of a grinding or other disintegrating apparatus, whereby the starch or sugar can be readily acted upon by the ferment, and brought into a condition where it can be subjected to the action of diastase.

It may be said that the *diastase* has the action of affecting changes similar to those effected by ferments, and is a substance present in malt; the latter of which is made by steeping barley in water until it germinates, and then dried off.

The diastase can only act under certain favorable conditions of temperature, and begins at about 35°F. This action is increased up to about 145°F., and under this temperature the *diastase* converts the starch of the mash into sugar. If the temperature is raised beyond 150°F. the action is decreased, and the best practice is to rapidly raise the temperature to about 130°F. and then very gradually to 140°F.

The action of the diastase produces *saccharification*, or a series of compounds known as saccharates, which renders the mash capable of being acted upon by the ferment. The saccharification takes place at about 122°F., and as the correct fermentation temperature lies between 60° to 80°F., the mash must necessarily be treated to effect a rapid cololing. The lowering of temperature may be done in various ways by the circulation of a cooling fluid, and will not be discussed.

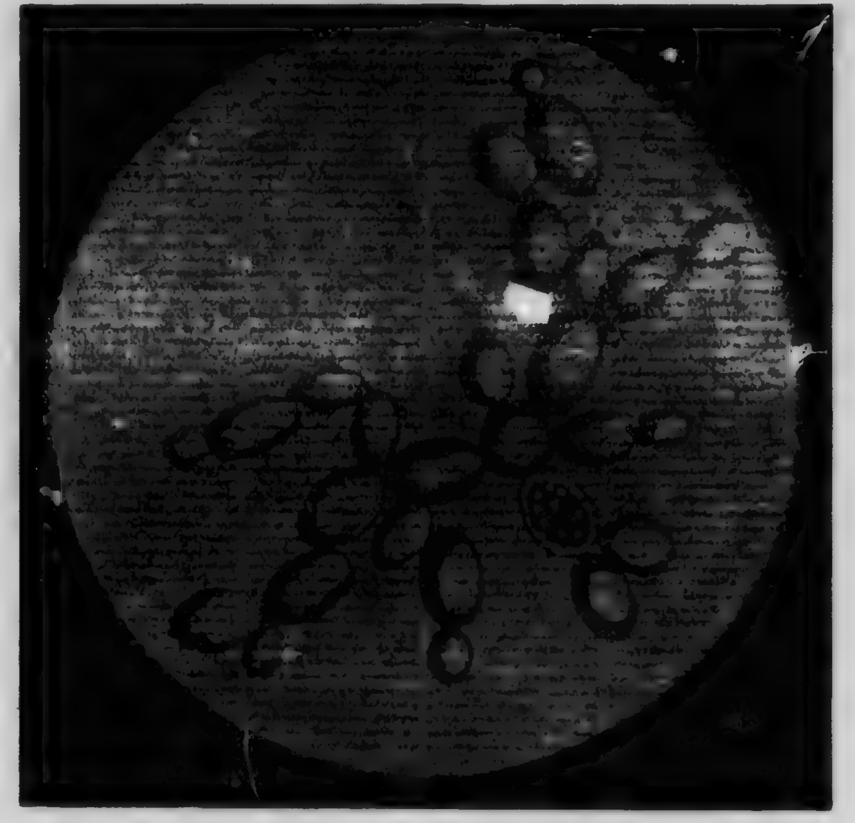


Figure 100

The ferment used in alcoholic fermentation is yeast, and it is essential that this substance be studied somewhat in order to understand its action more clearly. It may be said that yeast is composed of a mass of cells or corpuscles, having a diameter of .01 milimeter, and are arranged in clusters, as shown in Fig. 100. Their walls are an elastic membrane and their contents appear liquid or granular, when viewed through a microscope. They contain cellulose albuminoid matter, and mineral salts. When they are introduced into a substance that contains the material necessary for their development, they multiply very rapidly. This matter has been investigated very thoroughly by Pasteur, whose experiments corroborate the microscopic examinations, and leads us to the belief that the propagation of the cells is effected with extraordinary energy in liquids that contain, beside the yeast and glucose, a quantity of albuminoid matter ready formed.

The operation of fermentation may be divided into three equal periods, of which the first is that when the yeast mixed in the mash is growing; the second, when the growing of the yeast stops; and the third, when there is a reduction in the formation of carbon dioxide, and a lowering of the temperature.

In the first period the temperature should be about 82°F., as it is during the cooling of the mash that the yeast is propagated. The growth of the yeast is manifested by the development of carbon dioxide, and by a slight motion of the mash. When alcohol is produced to an extent of about 5 per cent. the growth of the yeast stops.

It is at this stage that the second period of fermentation begins, and the CO_2 is freely developed and the sugar converted into alcohol. The temperature at this stage should not exceed 81°F. This period of fermentation continues for about 12 hours.

At the end of this time the third period commences, in which there is a reduction in the formation of CO_2 and a lowering of the temperature to about 77°F.

The progress of fermentation is manifested by a number of different indications which it is necessary to observe. The insoluble constituents of the mash are forced to the surface, and form what may be termed a cover. If the carbon dioxide bubbles seldom break through the cover, it indicates that the conversion of sugar into alcohol is proceeding very slowly and imperfectly. If however, the cover is swirling and seething, or if it is rising and falling with an occasional discharge of gas, it indicates that the conversion is proceeding satisfactorily.

It is necessary, however, that the mash be prevented from foaming, as this invariably results in the vat flowing over, and thereby losing considerable of the mash. This may be prevented by pouring a little hot lard or petroleum into the vat, but not sufficient to interfere with the nature of the alcohol when distilled.

Towards the end of the second period of fermentation water is added in small quantities in order to dilute the alcohol in the mash, and thereby lower the percentage. This has the effect of stimulating further growth of the yeast, which results in a greater yield of alcohol per pound of starch. The theoretical yield of alcohol per pound of starch is 11.45 fluid ounces, but in practical operation it is only possible to obtain 80 per cent. of this, or about 9.20 fluid ounces.

After fermentation is completed, the mash may be in the form of a thick, diluted pulp, or in a thin liquor, according to various conditions, and the next step in the process is to separate the alcohol from it by distillation, as referred to later.

In the process of fermentation, the apparatus employed consists of a series of vessels made of oak or pine, bound together with iron bands. They are usually made with a greater depth than width, and are of various dimensions, according to the nature of the material to be fermented and other conditions. The vats, however, are made more or less similar in construction, and are slightly conical so as to present as small a surface as possible to the action of the air. The circular vats are generally recognized to be more suitable than square ones, in that they are better adapted to retain the heat of their contents. The lid of the vat should be securely closed during operation, and a portion of it should be made to open wihout uncovering the remainder. It is apparent from previous remarks that the temperature of the vats is a very important factor in fermentation, for which reason it is essential that the vats should be supplied with means for controlling the temperature to a definite degree. This is advantageous effected by having a copper coil at the bottom of the vat connecting to a steam and cold water pipe, so that it can be used for either heating or cooling. The diameter of the coil varies with the size of the vat.

It occasionally happens that iron vats are used having a jacketted space around them into which a heating or cooling fluid is circulated. The iron, however, is rapidly worn out by the corrosive action of the contents, and it is recognized that the wooden vats are the most economical.

It is necessary that wooden vats be frequently cleaned and disinfected, and it is common practice to cover the interior with linseed oil or varnish after each scrubbing period. It is also necessary to provide means for stirring the mash, and these range from simple hand-operated paddles to ingenious mechanical devices.

DISTILLATION: The constituents of liquor possess widely different degrees of volatility, and the first substance which distills is alcohol, owing to its comparatively low boiling point. If the distillation is carried far enough, the water is the second fluid to come over, and finally, there may be a portion of acetic acid and oily matter.

The object of distillation in this case is to separate the alcohol from the other substances as completely as possible, and it is, therefore, essential that the temperature of distillation be kept down as low as it is possible to volatilize the alcohol. A reference to the following table will clearly show that the temperature of distillation should be in accordance with the strength of the liquor, and should be a little below the boiling point of water.

TABLE 14.
ALCOHOLIC SOLUTIONS.

Percentage of Alcohol in Boiling Liquid.	Temperature of Liquid Degrees F.	Percentage of Alcohol in condensed vapor.
92.00	171.00	93.00
90.00	171.50	02.00
85.00	172.00	91 50
80.00	172 70	90 50
75.00	173.60	90.00
70.00	175.00	89.00
65.00	176.00	87.00
50.00	178.10	85.00
40.00	180.80	82.00

TABLE 14.—*Continued.*

ALCOHOLIC SOLUTIONS.

Percentage of Alcohol in Boiling Liquid.	Temperature of Liquid Degrees F.	Percentage of Alcohol in condensed vapour.
35.00	182.60	80.00
30.00	185.00	78.00
25.00	187.10	76.00
20.00	189.50	71.00
18.00	191.60	68.00
15.00	194.00	66.00
12.00	196.10	61.00
10.00	198.50	55.00
7.00	200.60	50.00
5.00	203.00	42.00
3.00	205.10	36.00
2.00	207.50	28.00
1.00	209.90	13.00

It will be seen from the previous table that by the distillation of an alcoholic solution, the percentage of alcohol in the condensate relatively increases in proportion as that contained in the original liquor diminishes, from which it is apparent that a very weak liquor can be strengthened to an alcohol pure enough for commercial use as a fuel by a second or third distillation according to the original strength. Referring to the table, it is seen that a one per cent. liquor will distill into a 13 per cent. in the first distillation, and a second distillation will increase the 13 per cent. liquor to about 63 per cent., and finally, the third distillation would concentrate it to a 90 per cent. alcohol. It must be clearly understood however, that these are theoretical values of the vapours immediately after the distillation commences, and as the evolution continues the vapors proportionately become weaker in alcohol. Assuming that the original liquor contains 5 per cent. alcohol, the vapors which come over at the boiling point will contain about 40 per cent. alcohol immediately after the distillation commences. As the alcohol is liberated from the still, the liquor proportionately becomes weaker, and consequently must yield weaker vapors. It is apparent that by stopping distillation at a given point before the alcohol in the liquor has become completely volatilized, the distillate will be considerably stronger than if the process had been carried to the end. It is evident from the above that, whilst it is possible to recover nearly all the alcohol by repeated distillation, it is impractical to carry the distillation to a point at which the condensed vapors become too weak and impure.

DISTILLATION APPARATUS: The essential parts of all distillation apparatus consists of a vessel called a *still* in which liquor is raised to the temperature at which vapors are given off, and a condenser by which the vapors are brought back to a liquid by a cooling system.

The still may be of almost infinite variety and may be heated by the direct application of a furnace, or by live steam applied direct or indirect by means of a coil. The sinplest form of distillation apparatus is illustrated in Fig. 101, in which *S* is the still, which when used for alcoholic solutions is made of tinned copper, or other metal not attacked by alcohol. The hot vapors pass through the outlet *O* of the still, and through a coil of tinned copper pipe *P* located in the condenser *C*. The material of which the condenser is made is of little consideration, in that it acts only as a receptacle for water to effect the cooling of the distilled vapors. It is necessary that the water be kept in circulation, and the vessel is provided with an inlet at the bottom *i* and an overflow *f*. It frequently happens in small units that the still is made in two parts *S* and *S'*, adapted to fit into each other, so as to enable the still to be more easily cleaned. In these stills the joints are made on re-assembling by a mixture of flour and salt moistened with water.

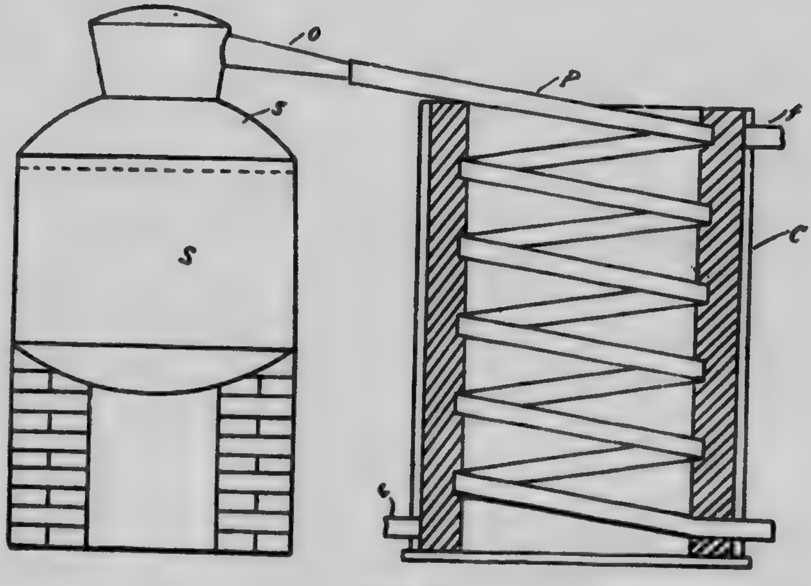


Figure 101

The condenser used in this apparatus rapidly cools the vapors from the still and brings the water and alcohol down together. In the operation of distillation apparatus, however, the vapors are generally collected in fractions, which necessitates the temperature of the condenser being kept at a definite degree. For instance, if the distillation is carried to the boiling point of water, 212°F. and the the first condenser is cooled to about 176°F., the greater part of the water vapor will be condensed, while alcohol which boils at 172°F. passes through the condenser as a gas and is brought down isolated from the water in a second condenser by lowering the temperature. Another factor of importance in designing distillation apparatus is the fact that when water vapors containing a small quantity of alcohol are brought into contact with an alcoholic liquid of lower temperature than the vapors, the water will be partially condensed, so that the remaining vapors will be proportionately richer than previously. The condensed water simultaneously imparts heat to the liquid interposed, and liberates a portion of alcohol present in the liquid, so that the uncondensed vapors are still further enriched.

In the apparatus referred to, however, it is frequently necessary to repeat the operation a number of times to bring the alcohol to a desired strength, and under average conditions it is more economical to employ compound distillation than resort to the simple method of repeating.

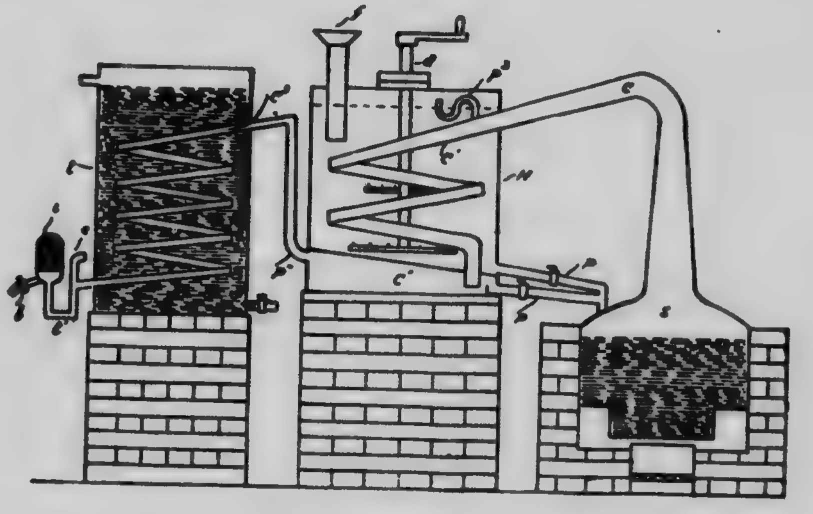


Figure 102

The principles of compound distillation is shown in Fig. 102 in which *S* is the still, having a dome-shaped head on the interior faces of which the aqueous vapors condense and run back into the still. By this means the vapors passing over the goose-neck connection *C* are richer in alcohol than when leaving the surface of the liquid in the still, and these are led into a mash heater *H*. The heater is provided with a coil C' which terminates in a compartment C'' connected by a pipe *p* to the still *S*. The mash heater is provided with a stirring device *d* to effect a uniform distribution of heat, and a pipe p' connects the heater to the still for passing mash thereto. A funnel *f* is adapted to admit the mash to the heater. At the top of compartment C'' a pipe p'' leads to a condensing coil C^3, located in a tub of cold water *t*. At the exit of the coil C^3, the tube is bent into a U-shape, as seen at t', one arm of which has a curved open ended continuation *e* through which air is expelled. The other arm opens into an inverted jar *i* containing a hydrometer for indicating the strength of the alcohol by its gravity. The jar is made of glass and frequently it has a black or colored background to permit easier reading of the hydrometer. The liquor passes over through a branch *B* into a receiver.

In the operation of this plant the mash is admitted into the heater until the tank is nearly filled, and a portion allowed to run over into the still through the pipe p'; the cock on the pipe then closed and a fire under the still started. The vapors which pass over the goose-neck connection are partially condensed in the coil C', and the condensed vapors flow into compartment C'', from which they flow to the still through pipe p. The removal of more condensable matter further enriches the vapors, and these collect in the highest part of the compartment C'' and pass through the pipe p'' to the coil C^3, where they are completely condensed. The passing of hot vapors through coil C' simultaneously heats the mash in the heater H and liberates a portion of alcohol, which passes into the coil through the bent pipe p^3.

The two classes of stills described are intended to illustrate the principles of distillation apparatus in general, and there are many modifications embodying these principles. However, from the foregoing, it is evident that by the employment of methods based upon these principles, it is practical to separate alcohol from water, and concentrate it to a definite standard at a comparatively small fuel expenditure.

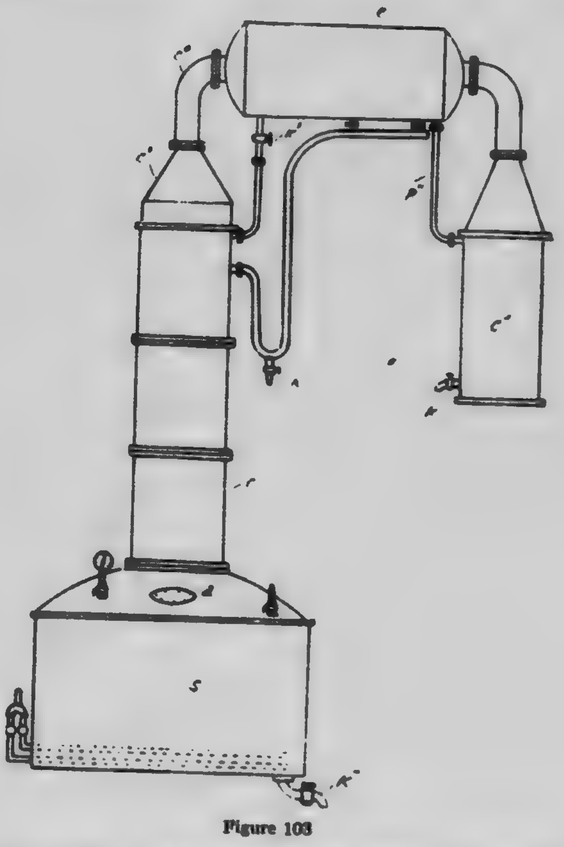


Figure 103

RECTIFICATION: The product of the distillation of alcoholic liquors do not usually contain sufficient alcohol to justify its employment for direct consumsumption. In addition to this, there are a number of acids which exist in fermented liquors. These are chiefly acetic and lactic acids, and frequently there are traces of tartaric and malic. It is also desirable to remove a series of compounds known under the general title of *fusel oils*, owing to their disagreeable smell. These oils, distilled at a temperature much higher than alcohol, and are therefore the last products of distillation, which results from raising the temperature of the boiling liquid for the complete evaporation of alcohol. The process of removing the undesirable compounds is known as *rectification*, and is carried out in modified distillation apparatus.

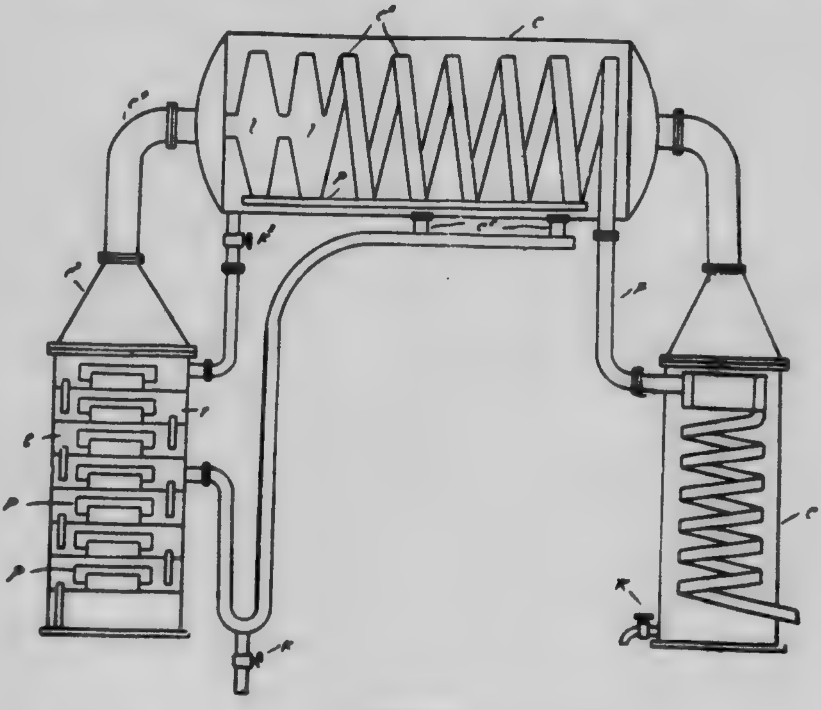


Figure 104

In Figs. 103 and 104, a design of rectifying still is shown, and consists of a still S, which is filled to about four-fifths of its capacity with the alcoholic spirit to be rectified. On the top of the still there is located a column C which contains a series of plates and this is connected with a condenser C' and cooler C'', which are filled with water. In the operation of the apparatus, the cocks K and K' are closed and the contents of the still heated by steam, which is introduced very gradually at the beginning. When the vapors of the heated spirit are given off, they pass by tubes t over each plate p in the column C, and escape through connections C^3 and C^4, into the condenser C', where they are brought down on contact with the lentils L and return in a liquid state through pipe p' and connection C^5 to the upper plate of column C. On returning to the column the liquid is volatilized and constantly re-charged with alcohol to be again condensed until the water in the condenser is hot enough to permit the lighter alcoholic vapors to pass into the coil C^2 without being reduced to the liquid state. When this takes place the vapors pass through p'' into the cooler C'' where they undergo complete condensation. The efficiency of this apparatus is considerably increased by the correct maintenance of temperature, and care must be taken to prevent the heat from becoming so great as to permit any of the vapors to pass over uncondensed, or flow from the cooler in a hot state.

The most volatile constituents come over first, and the spirit contains a large amount of acids. After this the condensed vapors gradually become richer and purer in alcohol, and finally the essential oils come over. The most impure products are separated from the remainder and re-distilled with the next charge. The process must necessarily be carried out very gradually, and it generally takes a few hours before alcohol begins to flow from the cooler. The purest grades are when the specific gravity is about .625 or between 92° to 96° Baume'. The operation is complete when the gravity rises to 1.05 or 3 to 4° Baume', but it is advisable to stop the still when the gravity reaches 1.00 or 10° Baume, as the products after this contain a comparatively large amount of fusel oils which lower the purity of the spirit.

After a charge has been rectified, the apparatus should be cleaned out each time, and this proceeds by opening the cock K'' and draining off the water. The contents of the condenser are then drained off in a similar manner by opening cock K^3, from which the liquid flows, to the plates of the column C and washes out the oils which have remained in them. The two cocks are then closed and the door d of the still head is removed. The water in cooler C'' is then run by means of a pipe into the still so as to partially cover the steam coil in the latter. The door d is again secured and a strong heat applied to bring the water in the still to the boiling point, and clean the apparatus by steam vapors. This is continued from 15 to 30 minutes, after which the steam is cut off and the still left to cool down gradually.

The capacity of rectifying apparatus has a direct influence on both the quality and quantity of alcohol obtained, and invariably a small unit is less suitable than a large one. For this reason it is found to be more economical to employ one large rectifying unit to take care of the spirit from a number of stills. The proportion of alcohol obtained from a liquor depends upon the nature of the spirit under rectification, which is, in turn, influenced by the nature of the raw material employed and methods of extracting the sugar. The average loss of pure alcohol during rectification is generally about 5 per cent.

ALCOHOL FROM FOODS.

POTATOES: The use of potatoes as a source of alcohol has been developed with remarkable success on the Continent of Europe, particularly in France and Germany. This food can be used under all conditions, but they are the most productive of alcohol when they are mealy when boiled, and in warm weather when they germinate.

In the process of alcoholic extraction the potatoes are washed and subjected to the action of steam under a pressure of 45 to 60 pounds per square inch. This breaks the coat and reduces the contents thereof to a pasty condition, where the starch is more readily acted upon by the ferment. It usually requires about two hour's steaming to reduce the potatoes to the proper condition, after which they are discharged to a crushing device and reduced to a pulp.

The pulp is then delivered to a vat, and about 150 pounds of broken malt introduced per ton of potatoes. Water is then run in at a temperature of 97° to 104°F., and the whole contents stirred up. The vat is then closed for half an hour, after which, boiling water is added until the temperature reaches 140°F., when it is left for three or four hours.

The contents are then built up to about 700 gallons per ton of potatoes by adding cold and hot water alternately, so as to finally bring the temperature down to 75° or 79°F. The ferment is then added, and consists of 5½ to 6 gallons of liquid brewers' yeast. This sets up the fermentation, which progresses very rapidly, and on completion the mash is distilled for the recovery of alcohol in modified apparatus particularly adaptable for materials of a pasty nature.

The process described refers to the original system and serves to illustrate the principles. In modern apparatus, however, the steaming and crushing are accomplished at one time under steam pressure comparatively higher.

The process of crushing and saccharifying potatoes by means of steam is comparatively high in fuel expenditure, and other methods are adopted which isolate starch without steam, and produce a mash of thinner consistency which can be distilled in ordinary apparatus.

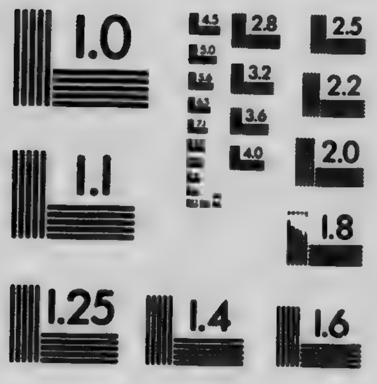
These methods require two operations which are (1) The reduction of the solid matter to a pulp by mechanical means; (2) The separation of the starch from the pulp. The mechanism employed for the reduction of the potatoes is applicable to other foods associated with garbage, and a reference thereto is essential.

One form of crushing apparatus consists of a cylinder having a diameter of about 24 inches. The cylinder is formed of alternate saw blades, which are kept apart by wooden washers. The teeth on the saws are set at an angle on the cylinder so that they do not slice the solid matter, but tear it up into a fine pulp. The cylinder revolves at about 800 to 1,000 revolutions per minute in front of an inclined table, having a jig whereby the matter is fed downwards against the teeth of the cylinder. The pulp falls into a receptacle beneath, and is placed on a sieve while the pulp is rubbed by hand. This is carried on until the water comes through clear, which indicates that all the starch has been washed out of the pulp, when the process is stopped, and the refuse on the sieve is destroyed. This refuse if of a woody nature and its value is discussed later in its consolidation into an artificial solid fuel.

The vessel in which the starch is finally discharged consists of a double bottomed tub, the upper one of which is perforated, and raised above the solid lower bottom. The tub has a capacity of about 530 gallons, and 5 to 10 pounds of chaff is spread over the perforated bottom. The pulp from 2,000 pounds of potatoes is then run in and allowed to drain for about half an hour through a cock located between the two bottoms. The pulp is then stirred while 250 gallons of boiling water is gradually added, which converts the matter into a paste. This is mashed with about 150 pounds of well steeped malt, and the liquid left to settle for three or four hours, during which time the starch is converted to sugar, and the liquid is known as sweet mash. It is then drained off

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc
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Rochester, New York 14609 USA
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(716) 288 - 5989 - Fax

through the perforated bottom into a fermenting tub, and the leavings in the preparatory tub mixed with about 125 gallons of boiling water and agitated. The liquid is again then drained off and the sediment sprinkled with cold water, and drained into the fermenting tub until the volume is about 750 gallons.

This process has been used in English distilleries, and objections have been brought against it in that the alcohol obtained is unpleasant to taste and smell. However, in this case the alcohol is desired as a fuel for industrial purposes, and these objections, therefore, appear to be no disadvantage. The process is productive of the greatest percentage of alcohol from potatoes, and it is possible to obtain 120 to 130 gallons of alcohol per ton of potatoes.

BEETS: The beetroot is cultivated and used throughout Europe, U. S. A., and Canada. These occur in many varieties, but the most important from an alcoholic standpoint possesses the following characteristics: (1) The pear-shaped with smooth skin; (2) The white with firm flesh; (3) Delicate and uniform structure, with a clean, sweet flavor and large leaves; (4) Average weight between 1.5 to 2.5 pounds. The specific gravity of juice from beets is the best guide of quality, and a juice rich in sugar is between 1.06 and 1.08. The roots are built up internally of small cells, each filled with a juice consisting of a watery solution of different bodies. These consist of phosphates, malates, oxalates, chlorides of potassium, sodium, and calcium, and several albuminoid bodies and pectinous compounds.

The composition of beets is approximately 85 per cent. water, 10 per cent cane sugar, and 5 per cent. woody fibre, albumen, and other compounds. The greatest part of the sugar in ripe beets is crystallizible, and when rich have a compostiion and properties similar to crystallized cane sugar, but in its natural state is contaminated with the aforesaid salts, and has, therefore, not the sweet taste of cane sugar.

The extraction of alcohol from beets may be effected in different ways.

(1) By reducing beets to a pulp in a rasping machine.
(2) By maceration with water and heat.
(3) By direct distillation of the beets.

In the first two methods the woody fibre of the plant is separated from the juice, and, as the fibre is of value in the manufacture of artificial fuel, these processes only will be referred to. The beets are first passed through a rasping machine and the pulp obtained is passed through a roller press, Fig. 105.

In this machine the pulp is forced upwards through a slide valve *V* and passages *p* under high pressure. The rollers *R R* revolve towards and nearly in contact with each other, and they are perforated so that the expressed juice may run off through the rolls. These perforations are conical with the apex of the cone in the rolls. A block *B*, located below the rolls, forms diverging passages which extend upwards on either side of the rolls, and down wards along the lower faces of the rolls to the point where they contact. This causes the pulp to be pressed with great force between the rolls, which in turn causes the juice to be forced through the perforations, and the woody fibre to pass outwards under the pressure bar *b'*. The pressure bar is regulated by set screws, and guides the residue to a passage *p'* leading to a vessel not shown. The rolls move at about 7 or 8 revolutions per minute, but the capacity of the machine is comparatively great and is capable of handling from 40 to 80 tons per day. The residue from the first pressing is macerated with spent liquor, and repressed a second time, after which it is considered of no value. The beet juice is led to a fermenting tub and the cane sugar present in it has to be inverted to grape sugar by adding a ferment before it will yield alcohol.

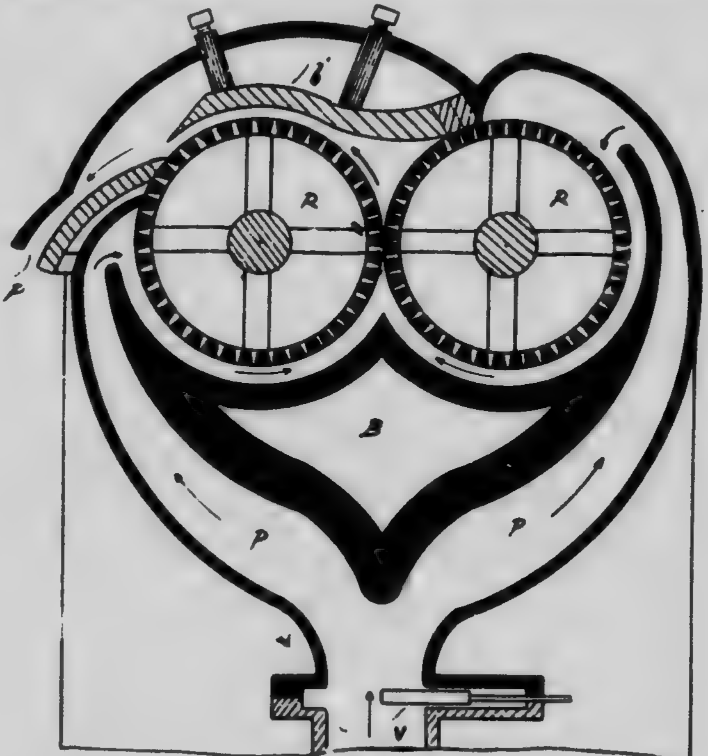

Figure 105

The extraction of alcohol from beets by *maceration* consists of slicing up the beets with a root cutter, and allowing the slices to macerate in a series of vats at definite temperatures. The size of the beets is somewhat important, and they should have a width of .4 inch and thickness of .04 inch. The sliced beets are covered with boiling water in a wood vat for about one hour, and 4 pounds of sulphuric acid added to the water for one ton of beets. The water is then drawn off into a second vat in which another charge of beets is placed and allowed to macerate again for one hour. The juice is again run into a third vat, where it macerates for one hour, and finally it is run into the fermenting tub. The first vat is re-filled with a new charge of beets and acidulated boiling water, and the juice allowed to flow to the second and third vat as previously. This is repeated a third time, after which the beets in the second and third vat are exhausted also. The residue is then removed and a new charge put in and the juice passed to the first vat for maceration for one hour.

The principle of this is made clear by reference to Fig. 106, in which four vessels are employed, and is known as a diffusion battery. The vessels *A*, *B*, *C*, *D*, each have a bottom sieve and top sieve, between which the beets are placed. From the bottom of the vessel *A*, a pipe p runs to the top of vessel *D*, and a pipe p' runs from the bottom of *D* to the top of *C*, and so on through the battery. A pair of pipes p'' and p^3 are connected to the top of each vessel for the admission of water and spent liquor or wash, respectively. A discharge pipe p^4 leads from each vessel to the collecting vat *V*.

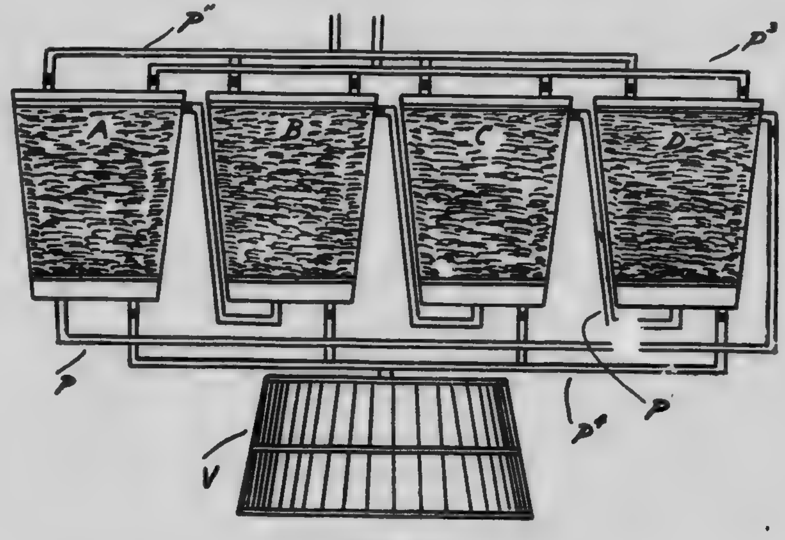

Figure 106

In the operation of these vats the slices of beets are placed between the sieves in vessel *D* and water or spent wash admitted at a temperature of 185°F. The beets are here allowed to macerate for 45 minutes, whilst in the meantime the vat *C* is charged with beets. When the time of maceration in vat *D* has elapsed, the cock on pipe p' between *D* and *C* is opened, and spent wash or hot water is admitted into vessel *D*, which forces the juice therefrom into vat *C*. When the vessels *D*, *C* are filled with liquid the flow is stopped, and the fresh liquid heated to 185°F., and again allowed to macerate for 45 minutes, during which time the vessel *B* is filled with beets. This operation is repeated until all the vessels are full, and when the maceration period has elapsed in vessel *A*, the vessel *D* is again filled with liquid and the beet juice drawn from *A* into the fermenting vat *V*. The beets in *D* are now exhausted, and the fluid in the vessel is drawn off and woody residue removed. The vessel *D* is again filled with beets, and the operation repeated, commencing with vessel *C*, and proceeding in the order of *C*, *B*, *A*, *D*. These successive charges and discharges continue and at the end of each period the first vessel is moved to the next; hence, the third period proceeds through *B*, *A*, *D*, *C*, and the fourth through *A*, *D*, *C*, *B*, when the fifth re-commences as the first and flows through *D*, *C*, *B*, *A*.

Before the juice is fermented it is brought to a temperature of about 82°F. in a boiler, and run into the fermenting vat with a small quantity of sulphuric acid. The amount of concentrated acid is about four pounds per ton of beets, or just sufficient to neutralize the alkaline salts and leave the solution slightly acid. About 9 ounces of yeast per 100 gallons of juice is then added to produce fermentation and an internal temperature of 68°F. is carefully maintained. The fermentation sets in very rapidly and is complete in 4 to 6 hours.

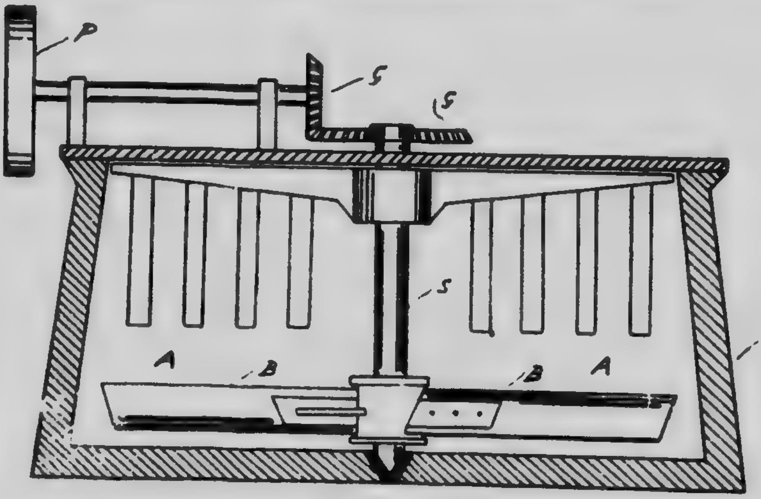

Figure 107

MOLASSES: The term molasses is applied to uncrystallized syrup, which constitutes the residue in the manufacture and refining of sugar used for domestic purposes. It is a dense, viscious liquid which contains about 50 per cent. saccharates, 25 per cent. organic matter, and about 10 per cent. inorganic salts, which are chiefly of potash. It varies in color from a light yellow to a very dark brown, according to its origin, and has a gravity of about .8235, or 40° Baume. The lighter varieties are the richest in sugar, but are not so widely employed owing to the fact that they are produced only from cane sugar, which is grown in tropical regions. The beet sugar industries make considerable of the darker varieties, and as beets can be grown in nearly all countries, they are of a greater source. This substance is rich in matter favorable to fermentation, and when it diluted with water the fermentation sets in. The molasses usually have an alkaline reaction, for which reason it is necessary to add acid after dilution. This is effected by adding about four pounds of sulphuric acid to every 20 gallons of molasses diluted with eight or ten volumes of water. The fermentation is hastened by the adding of brewers' yeast and begins in eight or ten hours and lasts from 60 upwards.

The process of fermenting molasses consists of first mixing the molasses with water to a certain dilution in a vat provided with a stirring mechanism. The mechanism employed in these vats is of varied description, but all of a similar principle, which is illustrated in Fig. 107. In this design the vat *V* is provided with a shaft *S* located in the centre and carrying radial mixing blades *B*. The shaft is driven through bevel gearing *G* and *G'*, from a source of power *p*. The rotation of the radial blades impart a circular motion to the molasses and water, and the projecting arms *A* impede up or break up the rotary current and cause thorough mixing.

The composition of molasses discharged from the sugar refineries contains from 30 to 45 per cent. of sugar, and this needs to be diluted with water until the composition is about 16 or 18 per cent. After the mixture is thoroughly set up, one gallon of concentrated sulphuric acid is added to 1,000 gallons of wash, to neutralize alkaline salts and leave the solution slightly acid. About 10 pounds of sulphate of ammonia is then added to give food to the yeast and stimulate fermentation.

The fermenting temperature of molasses wash varies somewhat with the concentration, and is higher as the concentration is greater. With a wash of 12° Baume, the fermentation begins at 77°F., and rises as fermentation proceeds. It should be kept, however, in the region of 82°F., as this temperature is the most productive to the growth of the yeast, and it is frequently necessary to pass a current of cold water through coiled piping to obtain this.

WHEAT, CORN, RICE and other CEREALS: The different varieties of cereals constitute probably the greatest portion of foods, and therefore constitute a large proportion of waste foods or domestic garbage. These cereals have been used to a comparatively great extent for the manufacture of so-called "Grain Alcohol," and all contain an abundance of starch, which, under the influence of diastase, is converted into fermentable sugar. In addition to the aforesaid cereals there are many other materials in close relation which contain starch in varied proportions, such as chestnuts, millets horse chestnuts, and other substances of this series.

The composition and alcohol obtainable from the commonest of these substances is seen from the following table:

TABLE 15.
ALCOHOL IN GRAIN

Substance	Starch	Gluten	Fat	Glucose	Cellulose	Inorganic Salts	Alcohol per 100 lbs.
Wheat	65.90	18.03	2.16	7.63	3.50	7.59	3.20 galls.
Rye	65.65	13.50	2.15	12.00	4.10	2.60	2.80 galls.
Barley	65.43	13.96	2.76	10.00	4.75	3.10	2.50 galls.
Oats	60.59	14.39	5.50	9.25	7.06	3.25	2.20 galls.
Indian Corn	67.55	12.50	8.80	4.00	5.90	1.25	2.50 galls.
Rice	89.15	7.05	0.80	1.00	1.10	0.90	3.50 galls.

The first operation in the treatment of grain is to grind it into a fine flour, and then steep it in a vat by pouring on hot and cold water in such quantities that after ten minutes of brewing the mixture will have a temperature of 75° to 95°F. This should cover the grain to a depth of 3 or 4 inches, and the mixture is now agitated for about ten minutes, and left to subside for half an hour. It is then stirred again and the mixture left to steep for 30 or 40 hours, according to atmospheric conditions and nature of water. In very warm weather the water should be changed every few hours to prevent premature fermentation.

When the grain swells and gives readily between the fingers, the steeping is sufficiently complete, and the water is run off. It is then mechanically agitated or ground if necessary to bring it to a condition at which it is favorable to fermentation and water is run into the mash tub in the proportion of about 7.5 pints per 1,000 pounds of grain. The temperature of the mash should now be in the region of 95° to 100°F., and to this it is necessary to gradually add boiling water until the temperature is between 145° to 165°F. The vat is then covered and left to stand for one hour to produce saccharification. This is manifested from the change from a white, mealy color to a dark brown; and also that it becomes thinner and more easily stirred and possesses a sweet taste.

It usually requires three mashings to extract all the saccharine matter from grain, and it is customary to boil down the liquor from the three mashings until they have a specific gravity of about 1.05. The liquor from a fourth mashing is used to bring down the whole to the correct temperature of fermentation.

MALTING: The greater portion of foods of a starchy nature possess matter which will cause them to germinate under proper conditions without the employment of artificial means. In practice, however, it has been repeatedly proven that they are saccharified more readily, and give a greater yield of alcohol, if they are mashed with a certain proportion of malt.

It should be stated that *malt* is made by steeping barley until it germinates, and at a certain stage interrupting its growth. This increases the diastase in the barley and the diastase is able to transform starch into a soluble form, and give lightness and liquidity to a wash containing it.

The best barley for malting is that which possesses the following qualities: (1) a thin skin; (2) a mealy interior; (3) of uniform structure; (4) of greatest weight. In addition to these it should be stored for at least three months before using. The barley has very slight germinating power when it is newly cut, but this is increased as it is stored. The necessity of uniform structure and weight lies in the necessity of uniform steeping, so that the period of germinating is the same for the whole body. In order to obtain a barley of uniform size, it is generally placed in a tumbling box of wire mesh, which eliminates the smaller grades along with the dust, seeds or other impurities.

In treating barley for malting it is first thoroughly washed, which may be accomplished by forcing compressed air into the tub This violently agitates and swirls the water therein, and washes away the impurities. The barley is then steeped in a tub of metal or cement in preference to wood, where cleanliness is more easily obtained. When the barley is placed in a tub, it should at all times be covered with fresh water to a depth of 3 or 4 inches, and for the first few hours the contents should be repeatedly stirred to ensure thorough wetting. The steeping time may take from 30 hours to 100, according to weather conditions; the colder weather being co-incident with longer periods; whilst in very hot weather it is necessary to change the water a few times to prevent fermentation.

The completion of steeping is indicated by it being entirely crushed when rubbed between the hands. When the barley is at the proper condition, the tank is opened and the water left to drain off thoroughly for about 12 hours.

The barley is now discharged to the malting floor, where it is spread out on the floor to a depth of 3 or 4 inches to dry for 10 or 12 hours, after which it is placed in a heap until it is warm to the touch. This may take from 12 to 24 hours. It is then again spread out to a layer of from 8 to 20 inches, according to the weather. During this time the *wet couch*, as it is now referred to, heats up, and after 25 to 30 hours produces at the end of each grain a small white sprout. The middle of the layer is the warmest, and therefore sprouts first, which necessitates frequent turning of the heap to give uniform heat, and thereby uniform germination. The height of the couch is now lowered to layers of from 2 to 6 inches, according to weather conditions, as previously.

The growth of barley needs both air and moisture, and the layer is made less to give it as much air as possible and simultaneously allow it to retain a certain portion of moisture by keeping it from being thinned out too much. At this stage the barley needs to be turned at least twice a day. The development of the barley causes small white sprouts to produce roots which are white and shiny. The appearance of these roots are a good indication as to the progress of germination, and if they begin to fade it is a sign that they lack water, and the barley should be sprinkled. When the roots or fibres of the grains are about half an inch long the germination is complete, and this may take from 6 to 12 days.

The effects of germination causes the barley to become sweeter; destroys the gluten; and liberates the starch. This change is particularly favorable to mashing and leaves the starch free to be acted upon by the yeast used in fermentation. The best time of the year favorable to malting is the spring, and when it is necessary to store malt for future use, it must be thoroughly dried.

The drying may be accomplished by the air in a warm, dry room in hot weather by spreading it in a thin even layer and frequently turning it. In colder weather, however, it is necessary to place it in a drying kiln. In this method the grain is spread out in a layer of 8 inches to one foot on the drying floor, and a fire maintained beneath the floor so that the drying room is about 95°F. at the beginning. From this temperature the heat is raised very gradually up to about 130°F., which thoroughly expels all the moisture. The drying completes the process and the barley is now known as malt. It is, however, advisable to screen it before using to eliminate the roots.

The previous description is intended to illustrate the malting in its simplest manner, and in the practical operation of large distilleries, the steeping, germinating and drying is carried out in a continuous operation by mechanical means. Figuratively, 1,000 pounds of barley will yield 1,250 to 1,500 pounds of green malt, about 900 pounds of air-dried malt, and from 800 to 875 pounds of kiln-dried malt.

CONSOLIDATION OF GARBAGE INTO SOLID FUEL.

In the preceding pages the writer has endeavoured to show that waste foods which are encountered daily from domestic life are of great value in the recovery of *industrial alcohol*. The foods referred to have been successfully employed in the manufacture of alcohol for use in distilleries, in the subsequent manufacture of various stimulating liquors. For this purpose it is evident that cleanliness in its manufacture is one of the most important items; for which reason garbage would be unsuitable. The time is drawing near when alcohol as a stimulant will be a thing of the past, and it behoves us to look into more economical methods of obtaining this spirit for commercial use as a fuel.

In considering domestic garbage as a source of raw material, it would first be necessary to provide mechanism to separate and tear up the organic matter from solid matter associated with it, before the organism was subjected to the action of grinding machinery. This does not appear to be a very difficult mechanical feat, and the writer is at the present time designing such mechanism.

When the organic matter has been fermented according to the principles described in the previous pages, there is a residue of woody fibre which can be economically consolidated into an artificial fuel. This fibre would invariably be discharged from the fermenting tub in a wet state, and the first consideration is to remove the moisture economically.

The amount of garbage produced is not nearly as large as the amount of solid fuel consumed, so that its consolidation into a fuel must necessarily be in connection with known methods of coking or briqueting. A briquetting process is more to advantage in the treatment of peat, lignite, or waste coal in the vicinity of production, which is generally in isolated districts. The domestic garbage, however, is produced in the cities where coke is also produced in connection with gas manufacture, and the coking process is, therefore, the most suitable for this material. In the manufacture of coke, the coal is decomposed and caused to take a new form which bears no relation to the original. This is caused by the influence of some natural characteristic of the coal, which has been attributed to [illegible] of a compound known as "carbene", $C_{22}H_{14}O_3$.

[illegible] manufacture of both coal and carburetted water gas, there is always [illegible] of hydrocarbons, which come down to a liquid when the temperature is [illegible] to that of commercial distribution. This matter comes under the general heading of "Tars," and is at the present time either burnt as fuel under steam boilers or shipped to refining concerns. These tars are very rich in heat-giving elements, and many engineers regard their use as fuel under steam boilers as unsatisfactory owing to their intense heat being destructive to boiler setting. These tars form an excellent binding material and have a tendency to promote coking, and by mixing 1 per cent. with garbage by a suitable spraying system, its adhesion is considerably increased.

Assuming that there are 10 pounds of garbage made to 100 pounds of solid fuel consumed, and that this is consolidated into a fuel by mixing with 90 per cent. of bituminous or coking coal, it is apparant that a considerable saving can be effected, and simultaneously obtain a fuel which is practically carbon. Briefly, a process designed to use this matter would in the writer's opinion consist of:

(1) Some economical means of evaporating the moisture.

(2) Spraying an adhesive substance, such as gas tar, whilst the garbage was being moved on conveying machinery.

(3) Mixing the matter with 90 per cent. of coking coal.

(4) Carbonizing in a retort or oven according to known methods.

The first reference, "Some economical means of evaporating the moisture," requires a little consideration, and the second and third references are purely mechanical operations.

In the manufacture of water-gas, the reaction consists of heating a bed of carbon containing matter to incandescence by an air blast, at a pressure which may vary from ten inches of water to three pounds. The oxygen of the air combines with the carbon of the fuel to form carbon dioxide with a total evolution of heat of 14.500 B.Th.U. per pound of carbon. This raises the carbon to incandescence, and on cutting off the air blast and passing steam through, water-gas is generated according to the reaction:

$$C+H_2O=CO+H_2.$$

This process consists, briefly, of an air-blasting period and gas-making period, which takes place alternately. In the air-blasting period the total evolution of heat cannot be caused to take place directly within the apparatus owing to the comparatively high blast pressures which are necessary to raise the carbon to incandescence for the water-gas reaction, and a large amount of sensible heat is driven up the stack. This heat could undoubtedly be employed for the drying of garbage by the addition of a special chamber.

Water gas is used as a base for oil gas in the enrichment of gases obtained from the carbonization of coal, or manufacture of coke, and is used by nearly all manufacturing gas companies. These apparatus are employed in cities from 5,000 population upwards, where there is also an accumulation of garbage, and it is evident that they could be advantageously employed for the drying of such matter with no extra fuel expenditure. The water gas process is described fully in a work, "Elements of Water Gas," by the same author, a second edition of which is now in preparation.

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